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GEOLOGY OF THE REGION ABOUT NATAL, RIO GRANDE DO NORTE, BRAZIL.

(PLATES XV.–XXII.)

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(*Received May 29, 1913.*)

INTRODUCTION.

The state of Rio Grande do Norte is one of the smallest in Brazil; it has an area of 57,485 square kilometers, and lies wholly within the tropics. The climate, topography and geology of this state may be taken as a type of the geology of the northeastern coast of Brazil.

Topographically the region is one of rather low relief, the climate is semi-arid, and in places the soil is thin. The general geology is simple, consisting of an old series of crystalline rocks, probably of Archean age, over and upon which rests a coastal belt of Cretaceous or Tertiary sediments having a width of about thirty kilometers. There are some mountains of fair size in the interior, but they are nearly all of granites or other crystalline rocks. None of these mountains lie within the area discussed in the present paper.

In 1909 I published in the *Bulletin of the Geological Society of America* a paper on the geology of the Northeastern Coast of

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Brazil that included all that was then known of the geology of the coast of Rio Grande do Norte from Natal to the southern edge of the state. That paper contained a sketch map showing the coastal belt of sedimentary rocks.

The work of Mr. Jenkins, done in 1911, has added much to our knowledge of the region, especially to the north of Natal, and it has definitely located the landward margin of the sedimentary beds.

It has also disclosed an unconformity in the sedimentary beds that seems likely to clear up the long standing question in regard to the existence of the break between the Cretaceous and the Tertiary in this part of South America. Some of my own geological observations made in 1911 have been incorporated in Mr. Jenkins' paper, while specimens of crystalline rocks from near Baixa Verde, examined microscopically and described by Mr. Jenkins, were collected by Mr. Earl Leib another member of the expedition.

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STANFORD UNIVERSITY, CALIFORNIA,
May 6, 1913.

INTRODUCTORY.

In the summer of 1911 the Stanford Expedition to Brazil made its headquarters for six weeks at Natal, in the state of Rio Grande do Norte, 5° 45′ south latitude, 35° 12′ west longitude. During this time most of the members of the party were engaged in collecting zoölogical material. Occasional inland trips were made which gave means for determination of geological data. These trips were along three lines, each of which went far enough into the interior, about forty or fifty kilometers from the coast, to reach the crystalline series of rocks:

1. To the northwest by railroad—"Estrada de Ferro Central do Rio Grande do Norte"—to Taipú and Baixa Verde.

2. To the south and southwest by the "Great Western Railway of Brazil," which extends for many kilometers down the coast.

3. To the west by boat up the Rio Jundiahy to Macahyba.

The ways by rail afforded the gathering of geological data by notes taken from the car windows, and by material collected at the various places where the train stopped. At certain points the party remained for several days and from these points horseback trips and walks gave data of more detailed character. These side trips were made around the towns of Taipú, Itapasaroca, Ceará-Mirim, and Extremoz.

A horseback trip from Carnahubinha to Macahyba and back into the interior, followed one of the contacts and gave familiarity with the general character of the country.

Thus the map was compiled from compass traverses, notebook sketches, railroad surveys, hydrographic charts, and the map of the region made by Crandall and Williams to the scale of 1 to 1,000,000.

Topographic Relief.

The Coast.

The vast stretches of sand are the most striking feature in the region about Natal and the northeastern coast of Brazil. The wind blows constantly up the coast to the northwest, driving the sand before it, filling up the stream mouths, banking against the low shrubs, sometimes planted by the people along the coast, forming a great range of sand-hills parallel to the coast. It is swept back by diverging currents over the low interior country for many kilometers covering up the soil and rocks, filling up the broad valleys, and forming long parallel sand-dunes all pointing to the northwest.

Underlying sandstones outcrop along the coast at various points. They form generally perpendicular cliffs from a few feet to about seventy-five feet in height as those of Barreiras do Inferno. These sandstones contain iron which is concentrated in certain places, hardening them into limonitic rocks that ring like steel when struck with the hammer. Sometimes all the pebbles of a portion of a beach are cemented together in this manner, forming a prominent point along the coast. These low points of dark, red-brown rocks and parti-colored cliffs of sandstone break the continuity of the white sand beaches. The wind, sweeping up the coast, banks the

sand at the points, forming a smooth straight shore line up to the south side, and leaving a little cove on the north side. Tall cocoanut palms may grow along the shores of this cove, waving over a tiny fishing village and a little church. The fishermen can here embark in their *jangadas* with greater ease than out on the windy south side of the point. Usually into such a cove a stream flows, if not, the people get their water by digging into the sand of the coast and a bubbling supply of sweet water is easily obtained. Sometimes one may see fresh water coming up through the sand right where the waves wash.

The sand is blown into the river mouths and tends to fill up their south sides, causing the streams to cut into their northern banks, where the sand is being swept away. Thus many of the streams turn, just before reaching the sea, and flow northward as they enter the sea. A view of a river's mouth from a vessel at sea shows a high range of sand-dunes on the south side, while to the north the country is low and rises gradually farther up the coast, where it culminates at another river mouth.

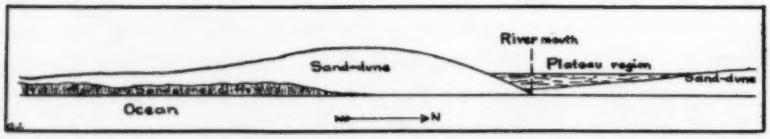


FIG. 1. A view from a steamer towards a river mouth, showing how the sand piles up at the south side of the stream.

There is often a hardened sand-beach in front of the mouth of such a stream, lying in a straight line parallel to the shore, where the fresh water meets the sea water. These stone reefs[1] have the general appearance of an ordinary sand bar, but they are hardened almost to a quartzite, and are difficult to break with the hammer. They contain white quartz sand and marine shells now found along the beaches. Often these stone reefs are found with no apparent stream behind them, but if one goes farther back into the country one may find an abandoned stream channel which formerly had an outlet behind the stone reef.

[1] J. C. Branner, "The Stone Reefs of Brazil," *Bul. Mus. Comp. Zool.*, Geol. Ser., VII., Cambridge, 1904.

The sea is shallow along the coast, and one sees this especially when watching the natives setting their *jangadas* afloat by pushing them along the wide, gently sloping beaches. Often at the end of

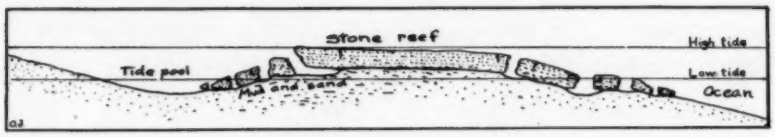


FIG. 2. General cross-section of the sandstone reef at Natal, Rio Grande do Norte.

one of the prominent points, as that of Pirangý, it may be noticed at low tide that the rocks extend for a considerable distance and then an organic reef, containing corals and other marine animals, continues far out to sea, forming a flat shelf for some distance. These organic reefs do not occur near shore, for the waves are full of sand, scooped up from the shallow bottom. The ships cannot come near shore, except through certain channels as that of Natal, where the animals that make up the reefs cannot live on account of the fresh water from the river.

The Valleys.—The most striking feature about the river valleys is their extreme width in comparison to their shallow depth. A small stream like the Rio Ceará-Mirim may flow through a valley two and a half kilometers wide not much more than fifteen meters below the surrounding region. The banks which fringe the wide valleys expose red iron-sandstones, covered with sand or a sandy soil. The valley alluvium is a darker black sandy deposit. The whole floor of the valley is flat, with a sluggish stream flowing down its center, bordered by swamps. The natives, whose mud houses are scattered or clustered in villages along its low sides, use it to advantage and cover most of the valley with their banana, corn, cotton, and sugar-cane fields. In some places, such as Ceará-Mirim, the region is very fertile and a growth of shrubs, trees and *carnahuba* palms covers the valley.

The valley, on the side of which Natal is situated, is about six kilometers wide, but most of this territory is silted up by mangrove swamps. The sea enters it and at high tide flows up to Macahyba

at a distance of about thirty-five kilometers, and returns at low tide. This action is utilized by the people who travel up and down the river only by tides. The present silting up of this great channel and many others like it is extremely interesting because it shows a sunken coast. The sea has intruded into the stream channels and later it has been driven out by the deposition of silt.

The Plateau Region.

The surrounding region is a low, sandy, gently rolling plateau covered with shrubs not much over two and a half meters in height. The small scrubby rubber tree is its typical plant. Farther back into the interior the hills become a more prominent topographic feature,

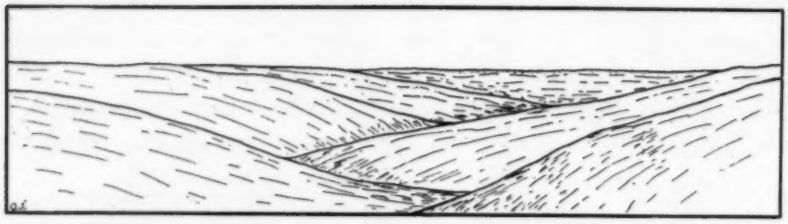


FIG. 3. Topography, looking from Taipú, in the rolling hills of the interior, towards the flat plateau region along the coast, Rio Grande do Norte.

for they are in the crystalline series of rocks. As one travels over the plateau region, its flatness appears unbroken, but occasionally

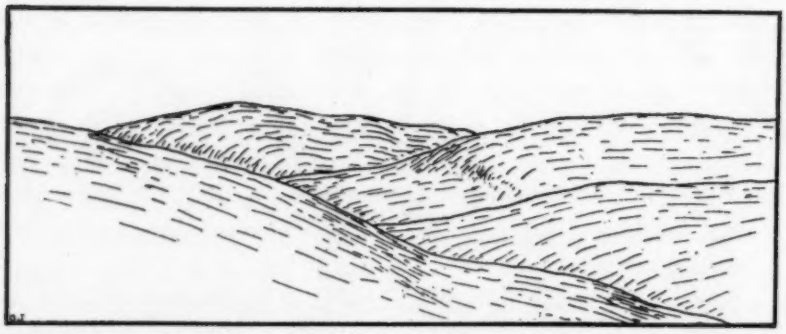


FIG. 4. Topography, looking northwest from Taipú in the rolling hills towards the higher, interior country, Rio Grande do Norte.

one comes upon the border of a wide valley with unexpected groves of *carnahuba* palms, fields of sugar-cane and bananas. A village with its quaint church, set on the upland, looks out on the fertile area while all the surrounding country is as dry and arid as a desert.

The farther one goes into the interior the more arid the country gets. The river valleys diminish rapidly in width, and low hills of crystalline rocks are rounded almost to flatness by age and decomposition. The granites tend to stand out as huge rounded domes, carved and grooved from weathering, while the gneisses and schists form the general base-level plain. The whole region reminds one of the deserts of Arizona with its dry, warm atmosphere, its cacti and desert shrubs, and its lack of water.

It is in a belt about ten or twenty kilometers wide along the coast that the rains have their most decided effect. This region is covered with numerous small fresh-water lakes. Some of them are connected with the ocean and some are not. In times of great rains they overflow and connect with each other. In times of drought some of them dry up completely, as Logoa Secca near Extremoz, a mere depression now which is said to have been full of water forty years ago. Often the lakes seem to have no outlet nor inlet, but if they are examined more closely they are found to be fed by springs occurring along the border just between the impervious clayey iron-sandstones beneath, and the loose wind-blown sand-dunes above. This was especially noticed in the case of Logoa Bom Fim, about thirty-eight kilometers south of Natal. Villages are scattered along the borders of these lakes and each has its cocoa-palm grove. The people are very poor and live on the little they are able to raise and the fish which are caught in the lakes. Other lakes are formed in the river valleys dammed in at the mouths by sand bars on the seacoast. These regions are the most fertile of all. Paparý is a typical example of such a place.

Areal Distribution of the Formations.

The sketch map of the region about Natal, given at the end of this paper, shows best the general distribution of the formations.

In the interior the rocks are crystalline: granites, gneisses, schists, shales, quartzites, and various forms of intrusive dikes. At Macahyba an engineer, who had been far back into the country, reported marble at a distance of about one hundred and sixty kilometers from the coast. This marble was said to have been like that found near Quixadá in Ceará, at the same elevation and relative location. The granitic rocks which are nearest the coast, in the region which this paper deals, occur at Macahyba, for here the river cuts deeply through the sedimentaries and exposes the older series.

Overlying the crystalline series are beds of fossiliferous limestone, lying almost horizontally, or dipping about 5° southeast, towards the coast, in layers of a few inches to a foot or more in thickness. This series is not well exposed. The principal localities for the exposures are at the railway cuts and at the quarries made in the limestones where they come to the surface along the sides of the valleys. Following along the contact of the granites with the sedimentaries one may find occasional indications of limestone on the surface. There seems to be a belt of this limestone, left from the great erosion the country has undergone, about ten kilometers in width. A few pebbles of limestone were found on the surface not far from Taipú, thus indicating a greater extent of the limestones in previous ages.

Unconformably overlying the limestones occurs an unfossiliferous iron-sandstone and clay series of generally unconsolidated material. The beds of this series are hard to distinguish, but they also seem to lie horizontal or to dip gently towards the coast. They extend in a belt about thirty kilometers in width along the coast. They are best exposed as sea-cliffs.

The wide river valleys contain a deep deposit of alluvium. This is an important factor in the geology of the country for these deposits are found to contain marine shells, showing the valleys were once filled with water from the sea, and later completely silted up. This process of silting-up is at present at work in some rivers as Rio Jundiahy and Rio Potengý, where it occurs about twenty-five kilometers inland. It is a mark of a submerged coast.

Over all the other formations a vast amount of sand is at present

being deposited along the coast, blown inland by the wind. The sand tends to fill up the river systems, for they are the lowest places. In time of drought the sand sometimes is able to gain complete control over some of the streams, stopping them up entirely. In time of great floods the water clears its channel again. A good example of damming by sand is the valley of Extremoz, where

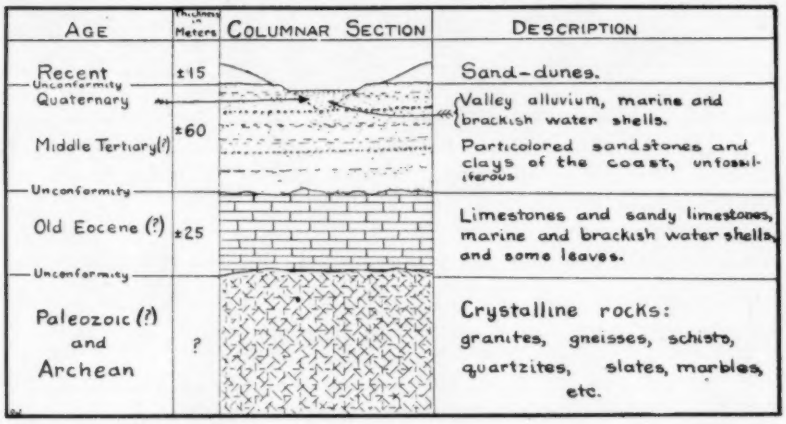


FIG. 5.

sand-dunes are heaped in the valley in longitudinal rows, while at its mouth is a great sand bank, twenty-five to thirty meters in height, lying across it at right angles. About fourteen kilometers inland Lake Extremoz lies in the forks of the old river channel, dammed in by this wind-blown intrusion.

DESCRIPTION OF THE CONTACTS.

The limestones lie unconformably on top of the old crystalline series. The contact was plainly seen at Alvoredo, about five kilometers north of Macahyba, in the bed of the Potengý River.

The sandstone and clay series lies unconformably on top of the limestones. At Jacoca, five kilometers southwest of Ceará-Mirim, the contact was observed in the limestone quarries. This showed the fossiliferous limestones in clearly defined beds, six inches or a foot thick, lying horizontally, with the sandstones rest-

ing unconformably on top. This unconformable contact is distinctly marked at these quarries and was carefully studied; photo-

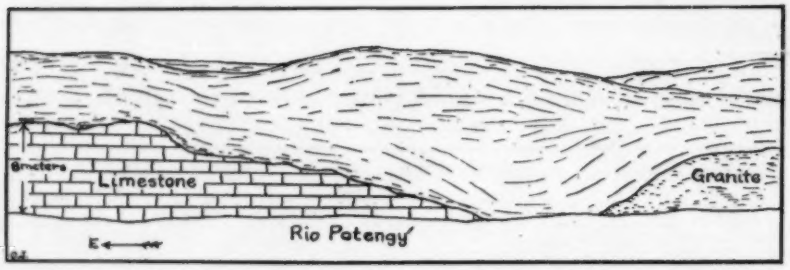


FIG. 6. An exposure along Rio Potengý showing the contact between the horizontal, fossiliferous limestones and the granites. Looking south, near Alvaredo, Rio Grande do Norte.

graphs were taken and material collected. At the point of contact the sandstone is very black, probably carrying manganese. Above this the sandstone has a soft white character, while on top lie the

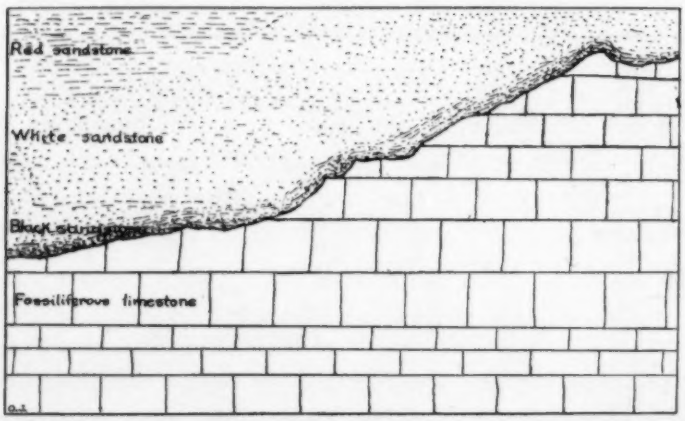


FIG. 7. Diagram made from a photograph of the unconformity between the fossiliferous limestones and the sandstone and clay series as exposed in a quarry at Jacoca, five kilometers southwest of Ceará-Mirim, Rio Grande do Norte.

red iron-stained rocks so common over the country. On the surface of the ground are loose boulders of the iron-rock. The bedding of the sandstone is not very clear, as in most localities, but has the general appearance of being horizontal.

The relation of the sand-dunes to the sandstone is clearly defined along the sea-cliffs. The older æolian deposits of sand lie cross-bedded on top of the horizontally bedded sandstone and clay series. Above these are blown newly formed sand-dunes.

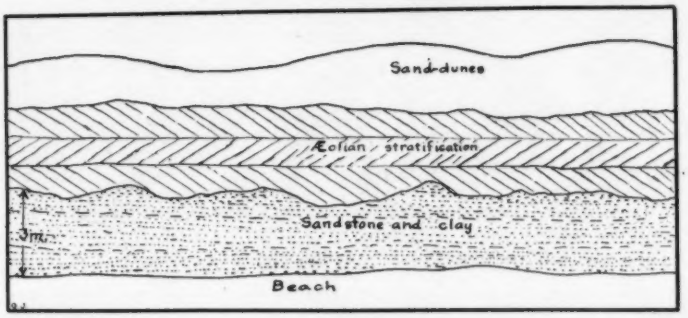


FIG. 8. Diagram of the bluffs at Ponte Negra, Rio Grande do Norte, showing the old æolian stratification with the newly formed sand-dunes lying on top.

The alluvial deposits are extensive, filling the wide river channels.

DESCRIPTION OF THE FORMATIONS.

The formations are described in this paper in the following order:

1. The crystalline rocks, probably Archean.
2. The limestones, of late Cretaceous or early Tertiary age.
3. The iron-sandstones and clays, which are later than the limestones.
4. The alluvial deposits.
5. The sand-dunes.

The Crystalline Rocks.

The railroad extends twenty-eight kilometers west of Taipú to Baixa Verde. The rocks of this region are crystalline, and a study was made of them here. Beyond Baixa Verde one or two kilometers, new railway cuts expose fresh specimens of these rocks, showing something of their general relation to each other. This part of the paper has been taken freely from the notes of Dr. J. C. Branner and Mr. E. Leib. Slides, made from the rocks collected, have been studied and the following report is submitted.

Decomposition has had a marked effect in leveling down this region, so that the natural exposures are only in the shape of flat bosses and exfoliated boulders. Mound-shaped hills, as that of Torreão Peak, which is about seventy meters high, lying three or four kilometers northwest of Baixa Verde, are composed of granitic rocks. On their surface are scattered great boulders of exfoliation, while at their base are bare, flat exposures of other crystalline rocks, giving to the whole the appearance of glaciation.

In all the railway cuts it was noticed that dikes of granites and pegmatites cut through micaceous schists. These dikes vary in width from one to thirty meters, sometimes following the plane of schistosity and sometimes cutting across it. Often one dike inter-

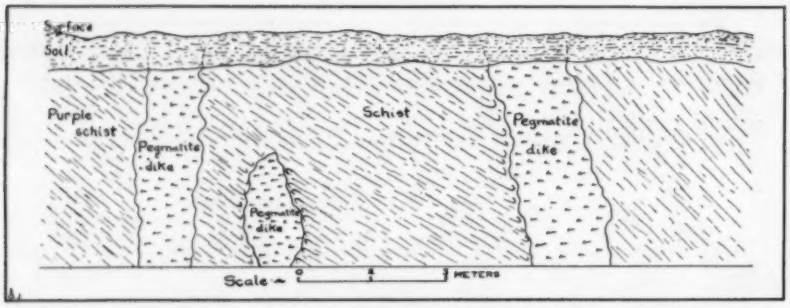


FIG. 9. Diagram of railway cut near Baixa Verde, Rio Grande do Norte, showing how the dikes intersect the schists and how the topography is unaffected by these.

sects another. These dikes and schists do not show in the topography; all are eroded and decomposed to the same surface level.

The following are descriptions of the rocks collected.

Quartzitic Arkose.—This specimen was collected near Taipú, kilometer 53. It outcrops in the region of dikes and schists. The rock is a medium-grained quartzitic arkose containing some minute cavities. Under the microscope the grains show that they are irregular in size and angular to subangular in shape. They are principally fragments of quartz, plagioclase, microcline, and orthoclase, all cemented firmly by opal. Chalcedony occurs as a secondary mineral, filling the minute cavities.

Quartz-Biotite Schist.—This was found at kilometer 49.5 near the place where the railroad crosses the Ceará-Mirim River, not far from Taipú. The rock is dark-colored, hard, rather fine-grained, containing quartz and biotite in great abundance. Its general appearance indicates that it may have been derived from some old sedimentary series. A slide shows quartz and biotite to be abundant as cemented grains. The feldspars are cloudy and hard to distinguish. Magnetite is scattered through the rock. There is some hornblende and tourmaline present.

Biotite-Schists.—In the cuts west of Baixa Verde granites and pegmatites cut through biotite-schists. Fresh specimens of these schists have a shiny, black or purple color. When weathered a little, the schists turn a brownish tint. In one specimen collected at the sixth cut beyond Baixa Verde, the following minerals appear in the slide: biotite in great abundance, quartz rather prominent, a considerable quantity of plagioclase and orthoclase, only scattering amounts of apatite and magnetite, and some garnet. Another specimen of this biotite-schist, which is partly weathered, shows some sillimanite.

Granite-Aplite.—A specimen from a dike cutting through the biotite-schists in the fifth cut west of Baixa Verde is a medium-grained, pinkish-white granite-aplite. Quartz grains are distinct. Muscovite and biotite are easily recognized in the hand specimen. With the microscope the following minerals were found: orthoclase and quartz are abundant; plagioclase and microcline are rather prominent; there is a quantity of titanite; both muscovite and biotite are present; some garnets and specks of magnetite are scattered through the rock.

Granite-Pegmatite.—Occurring as dikes, breaking through the biotite-schists, are granite-pegmatites. Some of them are graphic granites, and in some the quartz is scattered through irregularly. All of them are a light pinkish, decomposing to an almost whitish color, the feldspars changing over to sericite. A slide shows the following minerals: orthoclase, plagioclase, and quartz in abundance; microcline, rather prominent; biotite in patches; and tourmaline of a very dark variety. In one pegmatite there occurs a vein of red-

brown chalcedony. This may indicate that the schists were derived from old sedimentary rocks.

Granites.—The larger dikes which cut through the schists are usually granites. These rocks are medium-grained with a pinkish-gray color due to pink color of the feldspars. In one specimen the following minerals are in the slides: quartz, plagioclase, and orthoclase in great abundance; hornblende and magnetite prominent; titanite, garnet, and pyrite in smaller amounts. Other specimens from one of the larger dikes show a quantity of microcline and in addition to the other minerals zircon and apatite. In a specimen which came from a decomposed portion of the granites, sericite is prominent. The feldspars decompose leaving the mica flakes and the quartz grains prominent at the surface.

Log of Well at Baixa Verde, Rio Grande do Norte.

The following is a log of a well with a six and three-fourths inch bore taken at Baixa Verde, Rio Grande do Norte, at kilometer 84, elevation 162 meters.

	At – meters.
Gneiss	5
Dark granitic schist	10
Granitic rock, hard	15
Gneissoid granite	18
Schist	24
Fresh, hard granite, pinkish	39
Gneissoid granite, with dark streaks	43
Hard, gneissoid granite, pinkish	45
Greatest depth reached	46

From the above well, bored in crystalline rocks, it is clear that the gneisses, schists, and granites are intermixed and intergrade. This is typical of the way in which they occur in this country,—first one and then the other, with perfect gradation.

The Limestones.

General Description.—The limestones vary in color from light yellow to pure white. Some of the beds are bluish in appearance

and are hard and siliceous. Other beds are softer and limy, scattered through with sand grains, while others are almost sandstones. At the quarries, where the beds can best be studied, the more siliceous parts are cast away and the limy portions put in the kiln. The limestones usually show indications of fossils by small cavities and poor casts of shells and plants, but actual remains of animals themselves were not found. Metasomatic replacement of the shells by other minerals was not found to occur, although large irregular cavities give place for the deposition of silica in the form of quartz geodes.

A slide of the limestone obtained near Itapasaroca was studied. The following minerals in irregular grains were found in it: quartz orthoclase, microcline, and mica (biotite and also probably muscovite). The main part of the rock is a fine-grained carbonate containing both calcite and dolomite. Chemical tests showed some portions of the rock to be more dolomitic than others. It may be called a *magnesian limestone.*

Detailed Description.—The following are the principal localities studied where the limestone series is exposed in cuts:

1. Itapasaroca,—railway cut at kilometer 45, exposing limestone beds containing fossil casts of shells and plants.

2. Ceará-Mirim,—a quarry near kilometer 35. Limestone is exposed but there are no fossils.

3. Jacoca,—four kilometers southwest of Ceará-Mirim two quarries expose fossiliferous limestone beds. Here the line of the unconformable contact with the red-sandstones may be definitely traced.

4. Masaranduba,—fifteen kilometers north of Macahyba. A quarry is on the bank of one of the inlets to Lagoa Extremoz. There were only bare traces of fossils in the limestone beds.

5. Desterro,—seven kilometers north of Macahyba. A quarry in sandy fossiliferous limestone.

6. Alvoredo,—exposure on the bank of Rio Potengý, three kilometers north of Macahyba. Here limestone, with faint traces of fossils, lies directly on top of the granite, also exposed in the stream.

All expose practically horizontal beds, which have the general tendency to dip towards the ocean to the southeast. These lime-

stones are all obviously in the same horizon. Although each locality seems to have its own specific character and fossils, yet they all are more or less similar and are probably different facies of the same horizon.

Itapasaroca.

Half a kilometer beyond Itapasaroca, at kilometer 45, the railroad cuts through beds of limestone. This cut exposes four or five meters of the series. In the material thrown out of the cut, impressions of shells are abundant. In some of the rocks figures of plants, such as palms, occur. No good fossils could be found, but there is an abundance of material. The rock is a light or buff color. It occurs in beds of a foot or six inches in thickness. The strata stands almost horizontal or dipping slightly towards the sea to the southeast. In this exposure some of the beds have been slightly compressed into waves of about a meter in height. Beyond this cut is the old valley of Ceará-Mirim, and on its opposite side are the crystalline rocks, at a lower level than the limestones.

Ceará-Mirim.

About two hundred meters up the railroad from kilometer 35, near the town of Ceará-Mirim, a lime kiln is situated on the south side of the railroad track. One hundred meters or so up the hill from this is a limestone quarry. The hill forms the bank of the valley of Rio Ceará-Mirim, and the railroad skirts its edge. The beds at the quarry are practically horizontal, four meters being exposed in the cut which lies about 28 meters above the railroad track, whose elevation at Ceará-Mirim station, not far off, is 31.5 meters. Thus these beds lie about 60 meters above sea level. The material of the beds is very hard and limy. The fossils, which formerly must have been in this rock, have been completely obliterated by circulating waters. It was noticed at this quarry that the decomposition of the beds was aided by the action of roots of the shrubs, which opened cracks in the limestone allowing surface waters to pass readily downward. These waters carry with them iron from the sandstones above and deposit it in the cracks, leaving the

white limestones marked with streaks of red-brown. The hill above these beds is covered with thick scrubby vegetation. The soil is red and sandy, and lumps of the red iron-sandstone are scattered over the surface, showing that the sandstone beds lie above the limestones.

Jacoca.

Four kilometers southwest of Ceará-Mirim is situated the village of Jacoca in the valley of one of the inlets of Lagoa Extremoz. On the northern bank of the valley are two limestone quarries. These expose about four meters of limestone beds overlain, in certain places, by as many meters of the red-sandstones. The contact between these two series of rocks is irregular and unconformable. Each limestone bed is about a third of a meter in thickness, making a total of twelve beds. These vary in their content of lime and silica. Poor impressions of fossil shells are still left in the rock. The material is almost pure white in color and is a magnesian limestone with sand grains scattered through it. The contact line is irregular and shows that the limestones once underwent the reduction of erosion before the sandstones were laid on top. Between these beds and the sandstones is an area of black material which is probably a deposition of manganese. Above these are whiter sandstones of soft character, and still higher up are the red sandstones, characteristic of this latter series. On the surface of the ground are scattered boulders of the red iron-rock.

Masaranduba.

The village of Masaranduba lies in the valley of Rio Guargirú, an inlet to Lagoa Extremoz, on a road which leads from Macahyba to Ceará-Mirim, about half way between these two cities. One kilometer east of Masaranduba is a limestone quarry situated on the bank of the valley. The beds in this place are practically horizontal and unaltered. The exposure is four or five meters high. The material is of very pure limestone. It is white, and almost devoid of any fossil remains. On the hill above are loose pebbles of both limestone and iron sandstone.

PROC. AMER. PHIL. SOC., LII. 211 K, PRINTED SEPT. 16, 1913.

Desterro.

On the northern side of the broad valley of Potengý, north of Macahyba and near the place of Desterro, are some surface indications of limestone. Holes, a meter in depth, have been dug in prospecting for limestone. The material in these dug-outs is a yellow sandy limestone containing fossils, evidently in the same series as the other limestones.

Alvoredo.

On the southern side of the valley of Potengý, near Alvoredo and north of Macahyba, where the river cuts into its bank, is an exposure of about eight meters of limestone beds. These are horizontal. The material is the same as in the other localities with more sand and with more fossil impressions. Up the river, thirty meters or so, is a granite mass in place, standing about five meters high. Although bushes and soil hide the actual contact of the limestones with the granite, yet it was clear that the beds lapped directly on top of the crystalline rocks.

Fossils from the Limestones in the Region About Natal, Rio Grande do Norte.

The material collected from the fossil localities of the limestones in the region about Natal, Rio Grande do Norte, is exceedingly poor. Only casts and impressions could be found. In all they consisted of about a dozen different species of marine or brackish water shells, one questionable crustacean, and some plants, chiefly palm leaves. The limestones contained, in most cases, just enough sand grains to ruin the detailed character of the impressions. There were no definite horizon-marking fossils, but they all have the general appearance of being Tertiary, probably in the lower part of the series.[2]

[2] A collection of the fossils from the Rio Grande do Norte limestones was sent to Professor Gilbert D. Harris, of Cornell University, for examination, and he writes as follows of it under date of December 20, 1912: "Many of your specimens I judge belong to undescribed forms. Of the generic types I see none that might not possibly be anywhere from Cretaceous to recent, except perhaps the fragmentary impress of an Arca. None appear to

This material looks very much like that collected at Ponta de Pedras, which is supposed to be Eocene.[3]

The only fossil which is common to both these localities is *Cardium soaresanum* Rathbun.

The general character of the beds shows them to have been deposited in an estuary. This indicates that such a condition existed then as now along the coast of Brazil, *i. e.*, a sunken coast.

CARDIUM (CRIOCARDIUM) SOARESANUM Rathbun.

(Plate XX., Figs. 2 and 2a.)

Cardium soaresanum Rathbun. *Proc. Bost. Soc. Nat. Hist.*, Vol. XVII., Rathbun, "Cretaceous Lamellibranchs of Pernambuco, Brazil," pp. 253–255, 1874.

Cardium (*Criocardium*) *soaresanum* Rathbun. Extract from *Archivos do Museu Nacional do Rio de Janeiro*, Vol. VII., C. A. White, "Cretaceous Paleontology of Brazil," p. 90, Pl. VI., Fig. 6, 7, 8, Wash. 1888.

Cardium (*Criocardium*) *soaresanum* Rathbun. *Bull. Geol. Soc. Am.*, Vol. 13, p. 47, J. C. Branner, "Geology of the Northeast Coast of Brazil," 1902.

This is the only species that may be identified in all the material collected from the limestones of the region about Natal, Rio Grande do Norte. Numerous casts were found in every fossil locality and are easily recognized by the fine radial ribs, about 22 in number,

be distinctly Cretaceous unless the fragmentary impresses of a broadly turreted form showing some peculiar internal lirations should prove with other material to be a true Nerinæa. The fauna bears some resemblance in its little Chione forms to the Maria Farinha fauna, and though evidently representing a phase I am unacquainted with, I should be inclined to regard it as old Eocene. Still, as I said before there is not a single characteristic form wherewith to prove this statement."

The *Journal of the Academy of Natural Sciences of Philadelphia*, Vol. XV., lately published, has a paper on some fossils found at Trinidad in the northern part of South America. It settles the age of the Maria Farinha, Olinda and Ponte de Pedras beds definitely as Midway Eocene (pp. 32–33). The beds at Itapasaroca look precisely like those of the Midway Eocene beds, and each contains *Cardium soaresanum* Rathbun.

[3] J. C. Branner, "Geology of the Northeast Coast of Brazil," *Bull. Geol. Soc. Am.*, Vol. 13, p. 47, 1902.

each ornamented with minute points on its ridge. The specimens are small, about 12 mm. in height and width, and the thickness of the two valves is 6 or 7 mm. Inside casts are smooth and may be confused with the impressions of the sculptured outside.

Corbula (?) sp. ind.

(Plate XX., Fig. 1.)

This Corbula-like form is not like that recorded from Ponta de Pedras. Most of the specimens were 12 or 15 mm. long and 8 or 9 mm. high, but one specimen is twice that size. The beak is situated about a third the total length from the posterior end. No radial ribs appear in the impressions, but the lines of growth are very plain, standing out in marked relief. At the anterior end there is a raised portion, almost a ridge, running to the beak. The total angle made by the shell, taking the beak as the vertex, is approximately 120°.

This form is easily recognized by its smooth, even form and the distinct concentric lines of growth. It is abundant at the exposure in the railway cut near Itapasaroca, Rio Grande do Norte.

Cerithium (?) Mirimense Jenkins, new species.

(Plate XX., Figs. 8 and 8*a*.)

Many casts and impressions of a *Cerithium*-like form were found at the railroad cut near Itapasaroca, Rio Grande do Norte. The maximum height of the shell is nearly 15 mm. and the width of the lower part is 6 or 7 mm. The angle of the spire is 40° to 45°. Four or five ridges stand out on each half volution, running in the same direction as the spire, and alternate with the ridges on the adjoining volution. Spiral lines, 6 or 7, to each volution, run over the ridges and around the shell, following the volutions, and dividing the ridges into a row of little knobs. There are 6 or 7 volutions, which decrease rapidly in size as they approach the top of the spire. The aperture was not well preserved in any of the specimens collected. In one or two cases it looks as if it were oval-shaped. There is no sign of an extended canal.

This species is easily recognized by its very convex shape and the distinct sculpturing which is on its sides. Delicately ornamented cup-shaped impressions, left in the finer siliceous parts of the limestones, may be easily observed.

CERITHIUM (?) sp. ind.

(Plate XX., Fig. 4.)

At the locality near Desterro were found impressions of a *Cerithium*-like form unlike those found at the other localities. Length, 10 mm. to 12 mm.; width of last volution, 3 or 4 mm.; angle of the spire, approximately 25°. The volutions are about 8 in number, each convex in profile, and ornamented with spiral, slightly dotted lines following around the volutions. The aperture was not preserved in any of the specimens.

TURRITELLA (?) JACOQUEA Jenkins, new species.

(Plate XX., Figs. 7 and 7*a*.)

A broadly turreted form. The length is 25 or 30 mm. The width of the last volution is 12 or 15 mm. There are 8 or 9 volutions on the spire which comes to an angle of approximately 40°. Each volution is slightly convex in profile. The ornamentation is not distinctly visible on such poor material. There may be some sort of ornamentation following the center of the volution.

Many poor casts and impressions of these shells were found in the sandy limestones of the quarries at Jacoca, four kilometers southwest of Ceará-Mirim, Rio Grande do Norte. Inside casts show a double spiral coil following the volutions.

It is difficult to tell from such poor material whether or not this is a *Turritella*. If it proves to be *Nerinaea* it may place the age of the rocks in the Cretaceous. However this species is easily recognized by its broad form and may be of use in later correlation.

TURRITELLA NATALENSIS Jenkins, new species.

(Plate XX., Figs. 6 and 6*a*.)

A small, slender shell about 35 mm. long. The longest found was 50 mm. The diameter of the last volution is about 6 or 7 mm.

The angle of the spire is about 12°. The shell has from 16 to 22 volutions, usually 18 or 19, ornamented with two rows of tiny knobs situated at the borders of the volution, close to the suture. The row on the upper side is more prominent and becomes more so the nearer it approaches the top of the spire. In some of the younger or smaller specimens it stands out as a knobby ridge. There is another rather distinct row of knobs or points following the center of the volution. The material is so poor that it is difficult to determine anything further about the ornamentation except that it varies a little among different specimens. Some of the knobs are almost spines, appearing as little points, 6 or 8 on each half volution.

This form is not *Turritella elicita* as given by White, found at Maria Farinha and Ponta de Pedras. It differs principally in the ornamentation, having rows of points instead of ridges on the volutions. Also these rows are not situated in the same positions as in *Turritella elicita,* nor is the angle of the spire nearly so great.

The original shells were never found, so the casts were studied principally from wax molds made from them.

Associated with these fossils were *Cardium soaresanum* Rathbun, some *Cerithiums,* and a *Corbula*-like form. Apparently on top or interbedded with strata containing these were found casts of plant fragments, such as palm leaves.

Numerous casts of these *Turritellas* were found near Itapasaroca, Rio Grande do Norte, in the limestones exposed by the railway cut. In most of the other limestone exposures of this region these same forms occur.

Other Fossil Remains.

(Plate XX., Figs. 3, 5, and 9.)

Other fossil remains were found in the limestones. One appeared to be a portion of a *Pholas*-like shell; another, probably an *Ostrea* (Fig. 3). A larger bivalve, *Cardium*-like, about 25 mm. long and 20 mm. high, was rather common. A small *Cerithium*-like form (Fig. 5) with a sharp, smooth spire, making an angle of 40°, was found and is probably different from the other Cerithiums. A few specimens of a small gastropod (Fig. 9), something like *Natica,*

occurred in some of the beds. A small portion of a segmented animal, probably a crustacean of some kind, is also in this collection. The plant remains are principally impressions of fragments of palms and leaves of other plants. The principal importance of these plants lies in the fact that they indicate estuarine conditions of deposition.

LIST OF FOSSILS FROM THE LIMESTONES IN THE REGION ABOUT NATAL, RIO GRANDE DO NORTE.

	I.	J.	A.	D.
PELECYPODA:				
Cardium soaresanum Rathbun	*	*	*	*
Cardium (?) larger specimen	*			
Corbula (?) sp. ind.	*			
Ostrea (?)	*			
Pholas (?)	*			
GASTROPODA:				
Cerithium (?) *mirimense*, n. sp.	*			
Cerithium (?) sp. ind.				*
Cerithium (?)	*			
Natica (?)	*			
Turritella (?) *jacoquea*, n. sp.		*	*	
Turritella natalensis, n. sp.	*			
Crustacean (?)	*			
PLANTS:				
Palms, etc.	*			

Explanation.—I. is the railroad cut near Itapasaroca; J. is the quarry at Jacoca; A. is the locality near Alvoredo; D. is the outcrop near Desterro.

The Sandstone and Clay Series.

The sandstone and clay series which overlies the limestone is easily recognized by its peculiar character and color. It is a soft quartz sandstone intermixed and interbedded with sandy clay and with small pebbles up to boulders the size of a man's head. Its color is usually a brick red, but varies from white to a dark red-brown; red, blue, yellow, and lavender are some of the commoner shades. These sandstones must carry a large quantity of iron, for its presence is very noticeable at surface exposures. Along the sea-cliffs the leaching and concentrating is marked. It often forms perpendicular bands in the material, alternating hard red columns

to soft white ones, easily washed out by the sea. The harder portions of the concentrated limonitic deposits often form irregular shapes, leaving small holes and caves in which bats sometimes live. These more resisting portions may sometimes be left standing out as mere columns, breaking off before the beating of the waves. When these irregular rough pieces collect together they cement one to another and form a solid rocky point. So well is this cementing process carried on, that it is often hard to find a single loose pebble around a promontory. The soft leached parts of the cliffs are washed away and thrown up on the beach, where the wind carries them back over the country in the form of sand-dunes.

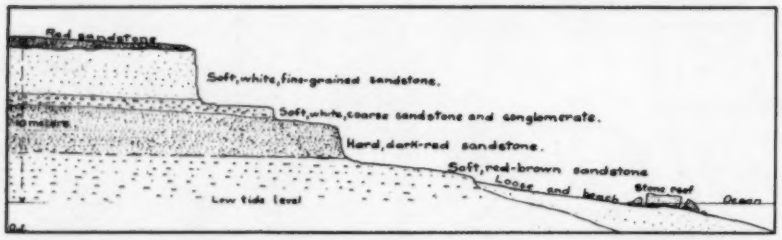


FIG. 10. A typical section of the sandstone series as exposed in a stream cut eight kilometers south of the fort at Natal, Rio Grande do Norte.

All along the coast from Natal to Busios the bed rock which is exposed is that of the sandstone series. The points named on the map and many other smaller ones are all made up of hard red-brown iron-cemented sandstones, which occur in irregular blocks broken down from an adjoining low cliff. In some places, as about eight kilometers south of the Fort at Natal and a hundred meters from the beach, the sandstone series has been cut through by a stream into deep, extremely narrow ravines. The beds are almost horizontal and the general surface is level, but these peculiar cuts break the surface, making it almost impassable although they are not much more than ten meters deep. It is a sort of Grand Canyon type of erosion. In such places bedding may be distinctly observed and the nature of the strata easily studied. The beds vary in texture from a fine soft sand or a clayey sand to a coarse conglomerate. These are interbeded, all carrying more or less clay, and varying in

hardness but usually rather unconsolidated. The amount of iron in the rocks seems to determine their color and also their hardness. These colors vary from white through all sorts of shades, especially red, brown, purple and yellow. Sometimes they are banded or streaked. Sometimes, as at Barreiras do Inferno, certain beds have concentrated all the iron. At this place the undermining action of the waves causes huge iron-sandstone blocks to break off and drop from a ledge three meters thick and these form a pile of irregular shaped boulders along the coast, all cemented together. These cliffs extend for about a kilometer along the coast. Their maximum height is twenty-five meters and they are perpendicular or sometimes overhanging. It is very difficult to pass back of them on account of the deep ravine structure formed there.

Just south of Barreiras do Inferno there are caves formed in the sandstone, which is harder and stands up better than in other places. These caves are formed by the waves at high tide. One cave was noticed which was one meter high, seven meters wide, and ran back five meters into the rock.

Usually the sandstone bluffs are not much over five meters high and the bedding is invisible on account of the peculiar banded perpendicular leaching. This was especially noticed at Morcego and at Pirangý. Here the iron is concentrated in perpendicular bands or columns, leaving a soft sandy or putty-like material in between. Over these bluffs the sand-dunes rest. Probably the rain, which sinks down through the sand-dunes, is regulated in seepage in such a way as to have this peculiar leaching effect on the beds below.

Farther into the country this sandstone series is easily recognized by its peculiar reddish color, visible especially along the low bluffs which border the wide valleys. Also it is seen where the wind-blown sand is only thinly scattered over the surface of the ground.

In all these beds not a single sign of any organic remains was found.

The vegetation on this series is always poor, scanty, and scrubby in form, sometimes almost entirely lacking.

Alluvium.

The only fertile land of the country is the alluvial deposits. They occur in the wide flat valleys as a black, sandy loam containing a good deal of plant matter. These deposits have been carried down by the rivers and washed in by the sea. In some places as in the river by Natal, this silting up has not yet been finished. Here mangroves act as a sieve for the sediments. In some places they have only left a comparatively small passage for the water, taking up at least four fifths of the entire valley, which is about six kilometers wide. Their many spreading roots retard the flow of the heavily laden water, which drops its load and thus fills up the channel.

Some marine shells were excavated from an irrigation canal made in the center of the valley of Rio Ceará-Mirim, about ten kilometers northwest of Extremoz and thirteen kilometers from the coast. From their preservation they look as if they were of Quaternary age. They occurred about a meter underground. The valley is very low at this point, said to be two meters above sea level. This shows that the sea must have extended up to this point, probably in a long narrow channel filling the river valley, and since then has been silted out, and possibly the country has been raised.

Borings for wells as far up as Carnahubinha bring up shells of the little rock oyster, *Ostrea equestris,* in great abundance. One well was sunk in the alluvium northwest of Carnahubinha, half a kilometer from Rio Jundiahy and at the depth of twenty-one meters a ledge of these oyster shells was struck. An Indian hammer head was also dug up from a depth of three meters in the alluvium, near the river at Carnahubinha.[4]

This is a deposit of more recent age; in fact the deposition may be observed now.

The most interesting thing about the alluvial material is its extreme depth. It extends below sea level. In fact all the valleys show this sunken condition, for they enter the ocean below sea level.

[4] Information obtained from Mr. John Charles Smith at Carnahubinha, Natal, Rio Grande do Norte.

The *carnahuba* palm is a typical plant of the alluvial deposit. It does not grow in the sandstone series.

This alluvial deposit in the valley occurs farther back into the interior than Macahyba. It could be seen as a wide flat depression many kilometers beyond this point, but its limit was not exactly determined.

LIST OF QUATERNARY SHELLS FROM AN EXCAVATION IN THE BED OF RIO CEARÁ-MIRIM, TEN KILOMETERS NORTHWEST OF EXTREMOZ, RIO GRANDE DO NORTE.

Pelecypoda.

†1. *Anamalocardia braziliana* Gmelin.
*2. *Arca* (*Scapharca*) *braziliana* Lamarck.
*3. *Arca* (*Cunearca*) *deshayesii* Hanley.
‡4. *Arca* (*Scapharaca*) *pexata* Say var. *holmesii.*
*5. *Cardium muricatum* L.
‡6. *Chione pectorina* Lamarck.
‡7. *Corbula swiftiana* C. B. Adams.
*8. *Divaricella quadrisulcata* d'Orbigny.
‡9. *Phacoides antillarum* Reeve.
†10. *Phacoides pectinatus* Gmelin.
‡11. *Laevicardium serratum* L.
‡12. *Macoma constricta* Bruguiere.
*13. *Ostrea equestris* Say.
‡14. *Pecten* (near *antillensis*).
*15. *Tellina lineata* Turton.

Gastropoda.

*16. *Anachis lyrata* Sowerby.
*17. *Bulla striata* Bruguiere.
*18. *Cerithium algicola* C. B. Adams.
*19. *Cerithium thomasiae* Sowerby.
*20. *Hemifusus mono* Lamarck.
†21. *Nassa vibex* Say.
*22. *Neritina virginea* Lamarck.

Explanation.

* Shells compared with those collected on the Branner-Agassiz expedition to Brazil and identified by Dr. Dall.[5]

[5] W. H. Dall, "Molluska from the Vicinity of Pernambuco," *Proceedings of the Wash. Acad. Sci.*, Vol. VIII., pp. 139–147. April 15, 1901.

† Shells compared with those from collections from Florida. These are also listed in this same paper of Dr. Dall's.

‡ Shells identified by Dr. Dall, November 21, 1912, who says:

"These shells are (except *Pecten*) identical with West Indian forms

now living, most of which also live on the Brazilian coast. The *Pecten* may also be, but we don't happen to have it."

All the rest of the shells are West Indian forms now living. The age of the deposit is probably late Quaternary. The deposit is evidently estuarine, the sea having extended into the old river channel in a narrow embayment. The water was mostly salt, but partly brackish, for *Bulla, Cerithium, Neritina, Corbula, Ostrea,* and possibly *Arca* (making a total of nine species out of twenty-two) are brackish water forms. *Neritina virginea* is sometimes found even in practically fresh water.

Log of a Well at Natal, Rio Grande do Norte.

(Reported by R. H. Soper in a letter of Sept. 21–29, 1912, to J. C. Branner.)

"I give here the log of a well which was drilled about one mile [two kilometers] from the bridge, toward Natal, across the river from Natal, and on the low marshy ground which borders the stream. The figures are from Burgess, the driller whom you may remember as the German who drilled the well in the crystalline stuff at Baixa Verde. He kept samples systematically which I saw and from which I compiled this record.

Meters.	
0–32	All a blackish, sandy, sticky, clayey mud. All contains more or less water which is salty.
32–41	A sandy clay, mixed with pebbles and boulders of quartzite. The largest pebble in the sample was about the size of a hen's egg.
41–42	White fine-grained sandstone.
42–44	Yellowish brown, clayey sandstone.
44–46	Whitish clayey sandstone.
46–50	Fine-grained reddish sandstone with occasional large pebbles of quartzite.
50–55	Dark, fine-grained sandstone with some clay and a little mica.
55–57	Quartzite pebbles with chunks of a mineral which gives a sharp biting taste like sal ammoniac.
57–64	Dark colored fine-grained sandstone which gives place to a hard, coarse-grained sandstone.
64–67	Dark pebbles of quartzite with pieces of hard, coarse-grained, vitrified sandstone.
67–82	A very fine-grained sandstone with considerable clay. Very hard. Comes out wet and black. Is a grayish white when dry.
82–87	A hard, brownish, sandy clay. When wet it was very black and could only be removed from hands with kerosene. Had a bad smell.
87–88	Same as 67–82.
88–94	Same as 82–87.

94–103 Coarse, grayish, clayey sand.
103–107 A brownish and grayish fine-grained, sandy clay which is black when wet.

"I might add that the well stopped here. There was more or less water all the way down but none of a drinkable quality. The name of the place where this well is located is 'Porto do Padre.' Burgess told me that when the tide was high, the level of the water in the well was low and when the tide was down low, the level of the water in the well was up."

The Sand-Dunes.

The action of the sand-dunes on the northwest coast of Brazil is of great importance. It is best studied along the coast for there the waves sometimes cut into the banks and expose dunes of older ages. Cross-bedding is the general form which it takes, distinctly marked, and overlying the soft red sandstone series. The sand is composed almost entirely of white quartz grains. It is blown back from the coast and across the country. It forms long parallel hills of yellowish color across the railroad south of Natal just north of Pitimbú. Here it has been carried from Ponta Negra. This form is common all along the coast in a belt about ten kilometers wide.

An interesting work of the wind and sand was that in the valley Extremoz. At the mouth of the valley, which is about two kilometers wide, there is a bank of sand-dunes some thirty meters in height, completely shutting in the basin. This bank must have existed some time, for a small lake, bordered by cocoa-palms, is nestled in its crest. The valley back of it contains a series of long, narrow freshwater lakes more or less connected end to end, but distinctly separated on their sides by long parallel dunes running lengthwise up the valley, standing almost as high as the surround-

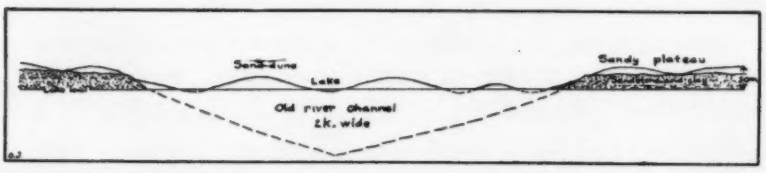


FIG. 11. Cross-section of the Valley of Extremoz, Rio Grande do Norte, showing the system of parallel lakes between the sand-dunes which dam it up.

ing low plateau. These dunes are of old character, dirty, and covered with vegetation. In some places the lakes are round, but usually they are long and narrow. They are bordered by little or no vegetation. Nearby a cocoa-palm grove may stand with its tiny village. This condition continues for ten kilometers up the valley to Logoa Agramara. Beyond there are a few meadows, dried-up ponds, and sand-dunes which close up the valley farther on. Logoa Extremoz is a horseshoe shaped body of water beyond the sand-dunes, situated at the junction of the two old river beds which go to form the main valley. This lake has a tiny outlet which runs into a marsh where it is dried up and sinks into the sand. The village of Extremoz lies on its northern shore and the railroad passes in sight of it. The general appearance of the lake as viewed from the car window was that of a river, not a lake. Further examination showed it to be a lake in an old river channel with two inlets, one at each of the ends of the horseshoe. "The fish fauna of Lake Extremoz is made up of the usual fresh water forms of the region and, in addition, many typical salt water ones, such as *Centropomus, Mugil* and *Gerras,* showing that the lake has been connected with the sea in recent years, though it is said to be cut off by sand hills at the present time."[6] These marine fishes are known to live for years in the fresh water of the tropics but are not known to spawn there. The habit of spawning in sea water is too great to be readily changed. At Ceará-Mirim only fresh water forms were found. At Paparý both fresh and salt water forms were found in the lake. The lake in this case, although dammed at the mouth by sand, has at present a direct connection with the sea. It is hard to see, in the case of Logoa Extremoz, how fish can ever get out or how they have existed, being away from the sea apparently for so many years. It is evident that at times of great floods the lake must connect with the ocean.

This damming in of fresh water is a common occurrence along the coast but not always on such a large scale. Paparý, which is farther down the coast, is a river basin partly dammed in by dunes at its mouth and made into a lake.

[6] E. C. Starks, "The Fishes of the Stanford Expedition to Brazil," p. 3. Stanford University, March 17, 1913.

The gaining of the dunes over the river is most probably done in times of drought, for then they can fill the river, cross it, and be carried into the valley.

Economic Geology.

Building Stone.

The crystalline series of rocks contains good building stones, such as granites. Far into the interior there are marbles, but they are rather inaccessible now. Granite is now quarried at Macahyba by the method of cooling the rocks suddenly by throwing water on them after they have been heated by fire. On account of the scarcity of large timber and its rapid decomposition due to climatic conditions and the work of such insects as ants, building stone is an important factor. The ordinary houses are usually made of mud with a reënforcement of slender limbs of shrubs and trees.

Lime.

The limestone series affords a means of making lime and cement. It is quarried where it is found exposed at the surface, but could be obtained at many other places if sought for. The quarries contain bedded rocks of varying economic value. Some of the beds are mostly siliceous, while others are almost entirely composed of calcium carbonate. Three specimens were dissolved in weak hydrochloric acid and gave the following percentage of insoluble matter, varying from 4 per cent to over 20 per cent.

Locality.	Percentage of Insoluble Matter.
Jacoca	10.5
Masaranduba	3.9
Itapasaroca	20.1

The limestone belt, occurring next to the granitic series, affords a means for obtaining cement to use in the same place in connection with the building stone.

Clay.

The clay in the upper sandstone series is sometimes quite pure. It is the material of which the native huts are made. In some places

the purest clay is used for making pottery and bricks. Ornaments, household utensils, such as vessels for holding water, are made at Santo Antonio and at Barreiros. These vessels are red-brown in color and rather easily broken. They appear to have been patterned after Indian styles, which may be a result of the Indian blood in some of the people of this region.

Soils and Agriculture.

The distribution of plants in this region is very striking; they are dependent upon both soils and climate. Thus the rubber tree and other shrubs grow over the sandy plateau region. Farther into the interior the region is arid, almost a desert. Here the soil is of decomposed granites and other crystalline rocks, and cacti and desert shrubs are the principal plants.

Bordering the great valleys, in the old alluvial flats, the *carnahuba* palm is the prominent tree, although this region produces many other plants more or less intergrown. Occasionally forests of trees as high as twenty meters may be found in these old filled-in valleys, as the forest between Monte Alegra and Desterro.

The mangrove swamps are typical of the borders of the estuaries and streams. Here deep black mud is deposited. This alluvium is what makes the fertile soil.

Along the beach one might suppose that there was no vegetation, but on the shores of almost every little cove there is a grove of cocoanut palms and a little fishing village.

The valleys contain a great deal of sand, but are on the whole fertile. The natives use the most primitive methods in farming. There was not a single plow seen about Natal. The soil contains enough sand to keep itself fairly loose and the plants are simply stuck in the ground and left there. Bananas, sugar-cane, cotton, corn, and various kinds of tropical fruits are raised. Occasionally coffee bushes are grown in the shade of other trees. Mandioca is raised in great abundance. Its root is made into farinha, the principal food of the common people.

At Carnahubinha there is a cotton-seed oil factory. Also at this place salt is concentrated from the sea water which flows up the Jundiahy at high tide.

Water-Supply.

The abundant rains along the coast sink into the sand immediately, but on coming in contact with the clayey beds of the sandstone series below, they are not able to pass farther down, so they emerge at low places. These low places are often between sand-dunes. Thus along the sea-coast, natives draw water from holes dug in the sand and the water is soft and fresh.

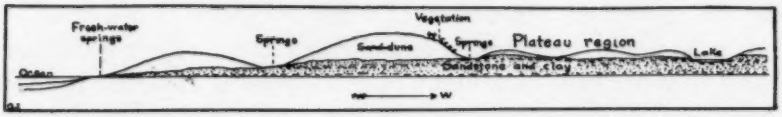


FIG. 12. General section of the coastal sand-dunes, showing how the fresh-water springs occur. Rain sinks through the sand-dunes and emerges where impervious beds of the clayey sandstones are exposed.

On the opposite side of the river from Carnahubinha there is a place called *Agua Doce*. Here excellent drinking water is obtained. The sand-dunes form an amphitheater around one side of the small depression, which is about fifty meters across. The water is bubbling up all the time and carries away the sand as fast as it is blown into it. Fresh water occurs in a certain point in the river near this place, although the river carries salt water from the sea. Here it is said that a hole twenty-two meters deep is present, while the rest of the stream has only the depth of six meters.[7] Similar holes usually occur near the bank where a sand-dune is present.

This form of spring supplies the small lakes of the plateau region with water the year around, as in the region north of Paparý. Here, along the border of some of the lakes, such as Logoa Bom Fim, such springs were found feeding the lake directly.

The rivers carry the water down from the interior. Often they are dammed at their mouths and form lakes. These lakes are valuable to the people, whose villages are clustered about their shores, as at Paparý.

Farther into the interior the lack of water is a serious matter. Sometimes great droughts drive the inhabitants from the country.

[7] Information obtained from Mr. J. D. Smith at Carnahubinha.

The occurrence of granitic rocks does not afford the means of obtaining underground water as in the region of the sedimentaries along the coast.

Effects of Climate, Etc.

All the ocean currents and the winds constantly sweep up the coast towards the northwest. The water is warm and the atmosphere balmy. The greatest rains and the hottest weather occur during the months of our winter. During our summer the rains are more scarce and the atmosphere cooler and drier. The region about Natal does not have such heavy rains as some of the other parts of Brazil such as those nearer the equator. In fact the country about Natal is very healthful.

The direction of the winds and the ocean currents affects the coast line in that all the bars, spits, reefs, and promontories tend to point up the coast to the northwest.

The stone reef at Natal affords the maintenance of a quiet harbor.

Effect of a Sunken Coast.

A sunken coast affords fine harbors. Cities occur at the points where arms of the sea extend up the river channels. Natal is a good example of such a city beside a harbor thus formed. The tides which flow up and down these channels give to the people an easy method of transportation.

Effect of Silting.

A constant annoyance to the people is the perpetual silting up of the channels and the shifting of sands and the formation of sand bars in their harbors. These things change rapidly, being dependent largely on the amount of rainfall, the flow of the rivers, and the intensity and direction of local currents.

Mangroves help the silting process to a great degree, but still these swamps when drained finally make up the fertile lands of the country.

The depth of the silt in the river channels often causes disturbance to the people when they attempt to drive piles in the mud and cannot find bed rock.

SUMMARY.

There are three principal series of rocks in the region about Natal: the particolored sandstones and clays, exposed as sea-cliffs; the underlying fossiliferous beds of limestone; and the crystalline rocks in which are schists, gneisses, quartzites, shales, granites, etc. The sedimentaries form a belt along the coast about thirty kilometers wide, while the crystalline rocks make up the interior country. Besides these formations the alluvial deposits in the valleys and the wind blown sands of the coast are important features of the geology of this region.

The most important results from this work are as follows:

1. The determination of an unconformity between the particolored sandstone and clay series and the underlying limestones.

2. The finding of fossils in the limestones.

3. The determination that the limestones were laid down as estuarine deposits, thus indicating a sunken coast at that time such as exists now.

4. The proof that the coast has sunken recently, and the commercial effect that this condition has had upon the country in affording fine harbors, and in making good agricultural land by the deposition of silt in the rivers forming fertile valleys.

5. The effect wind blown sand has upon the country in damming streams and thus forming fresh-water lakes.

6. The large supply of good water in the region of the sedimentaries in comparison to the lack of water in the dry interior.

LELAND STANFORD UNIVERSITY,
CALIFORNIA.

EXPLANATION OF PLATE XX.

FIG. 1. *Corbula* (?) sp. ind. Drawing from a wax mold.

FIG. 2. *Cardium soaresanum* Rathbun. Composite drawing from several wax molds.

FIG. 2a. *Cardium soaresanum* Rathbun. Showing inside cast of shell.

FIG. 3. *Ostrea* (?). Drawing of an impression of the shell.

FIG. 4. *Cerithium* (?) sp. ind. Drawing from a wax mold.

FIG. 5. *Cerithium* (?). Drawing from a wax mold.

FIG. 6. *Turritella natalensis* n. sp. Composite drawing from several wax molds.

FIG. 6a. *Turritella natalensis* n. sp. Showing inside cast of shell.

FIG. 7. *Turritella* (?) *jacoquea* n. sp. Composite drawing from several wax molds.

FIG. 7a. *Turritella* (?) *jacoquea* n. sp. Showing inside cast of shell.

FIG. 8. *Cerithium* (?) *mirimense* n. sp. Composite drawing from several wax molds.

FIG. 8a. *Cerithium* (?) *mirimense* n. sp. Showing inside cast of shell.

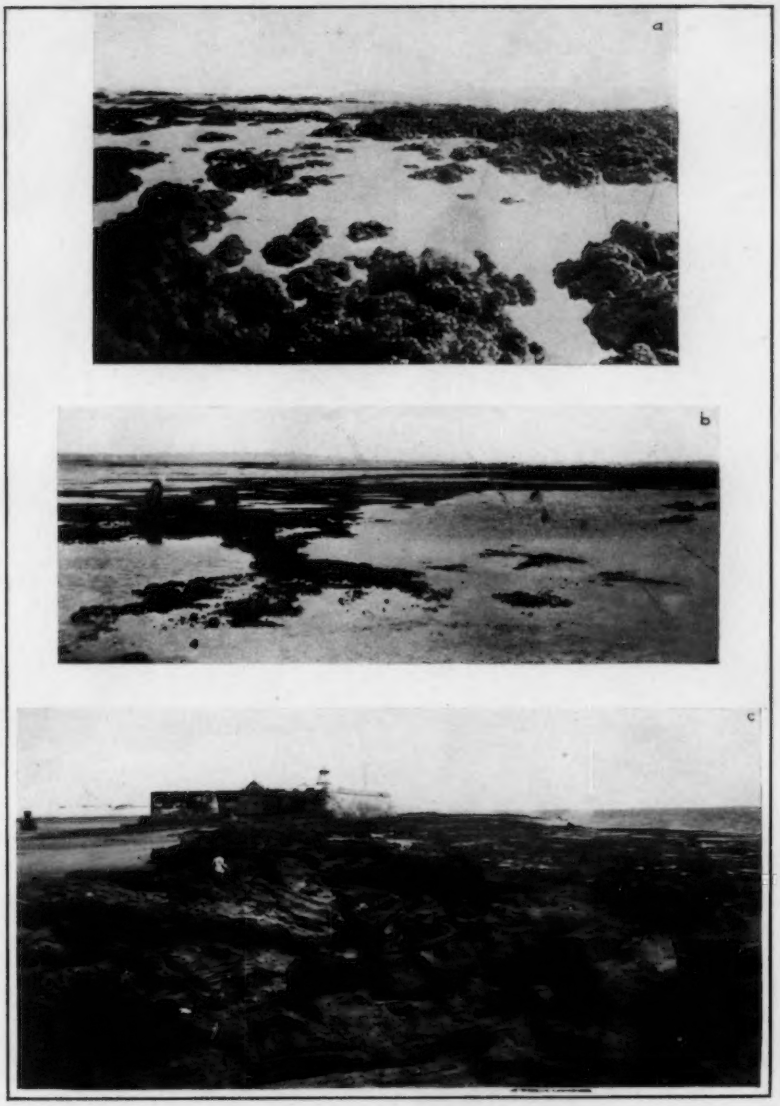
FIG. 9. *Natica* (?). Outline of the impression of the shell.

SANDSTONE REEF AT NATAL, RIO GRANDE DO NORTE.

FIG. A. Looking from the old fort along the reef, showing the stranded steamer on the reef at the far side of the bar.

FIG. B. Looking northeast along the coast from Asylo de Mendicidade, showing the same stone reef.

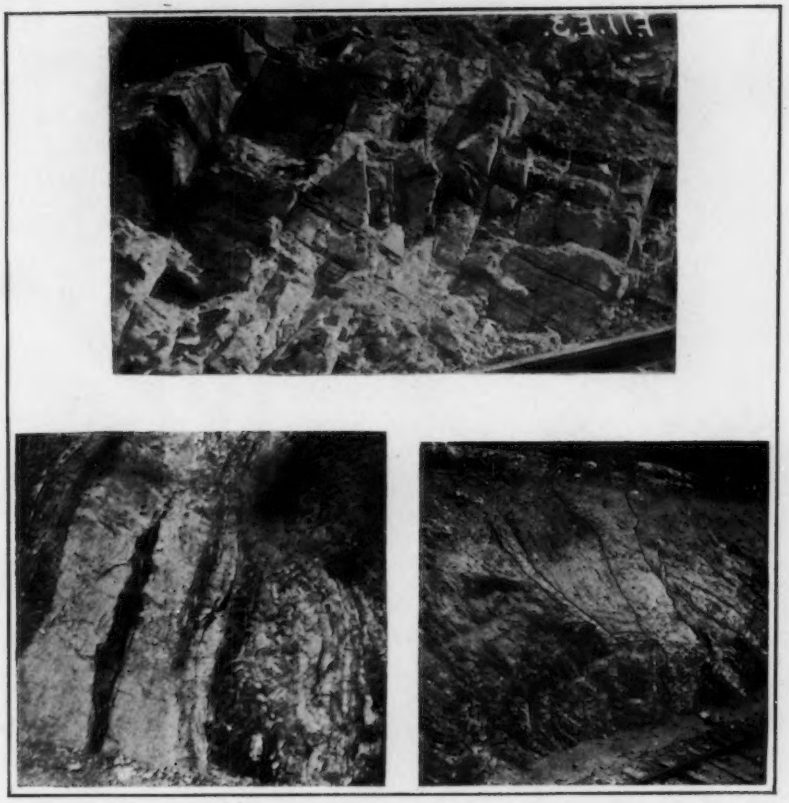
Photographs by G. A. Waring, 1912.



RIO GRANDE DO NORTE REEFS.

FIGS. A AND B. Looking north along an organic reef off the coast from Piringy. Photographs by E. Leib, May, 1911.

FIG. C. Looking along the sandstone reef at Natal toward the fort, showing etched and fallen blocks. Photograph by G. A. Waring, Nov., 1911.

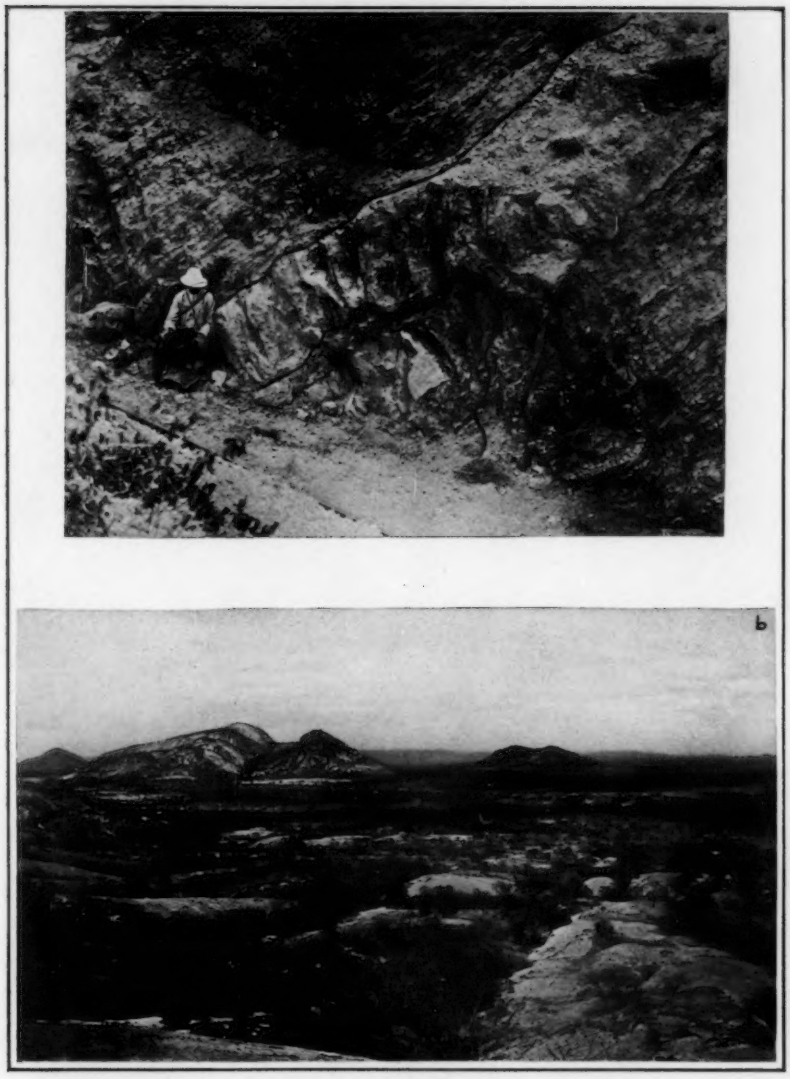


CRYSTALLINE ROCKS EXPOSED IN RAILWAY CUTS NEAR BAIXA VERDE, RIO GRANDE DO NORTE.

FIG. A. Showing weathering of the dike rocks in the third cut northwest of Baixa Verde.

FIGS. B AND C. Granite-pegmatite dikes in biotite-schists, second cut beyond Baixa Verde. Fig. c shows the levelling of the surface by decomposition. Topography is not affected by these dikes and schists.

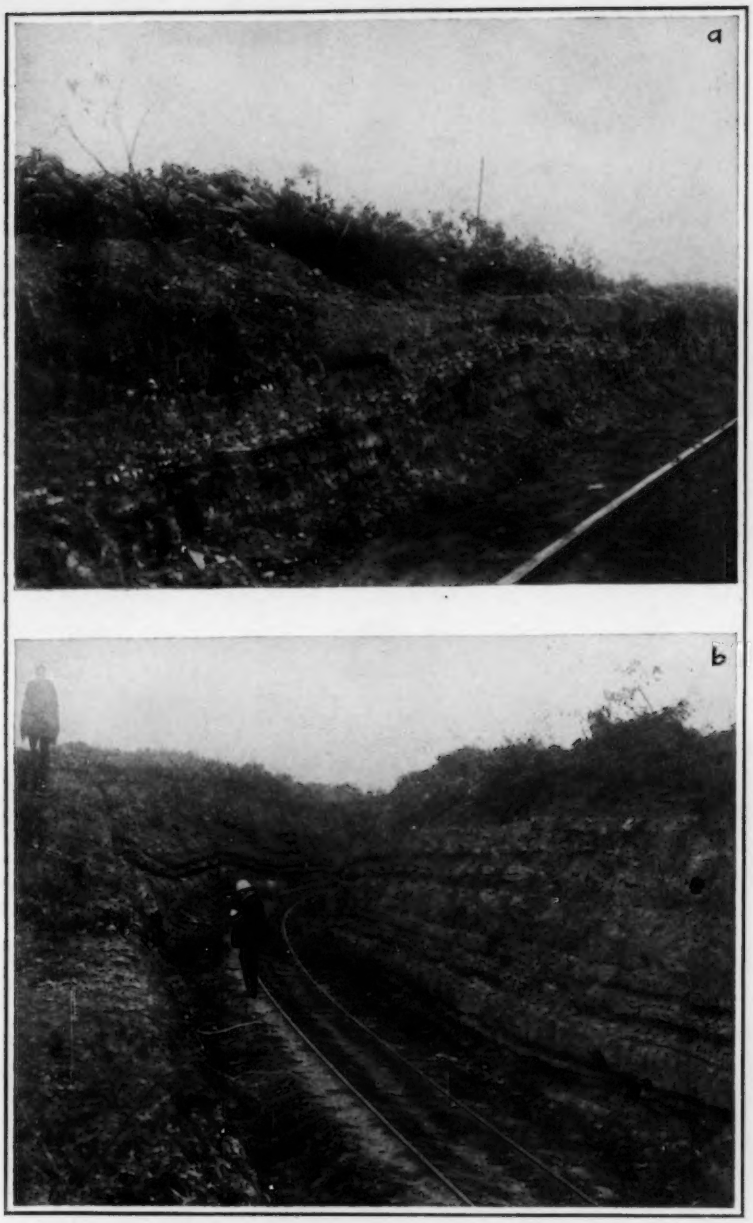
Photographs by E. Leib, May, 1911.



CRYSTALLINE ROCKS OF THE INTERIOR, RIO GRANDE DO NORTE.

FIG. A. Y-shaped pegmatite dike in biotite-schists near Baixa Verde. Photograph by E. C. Starks, May, 1911.

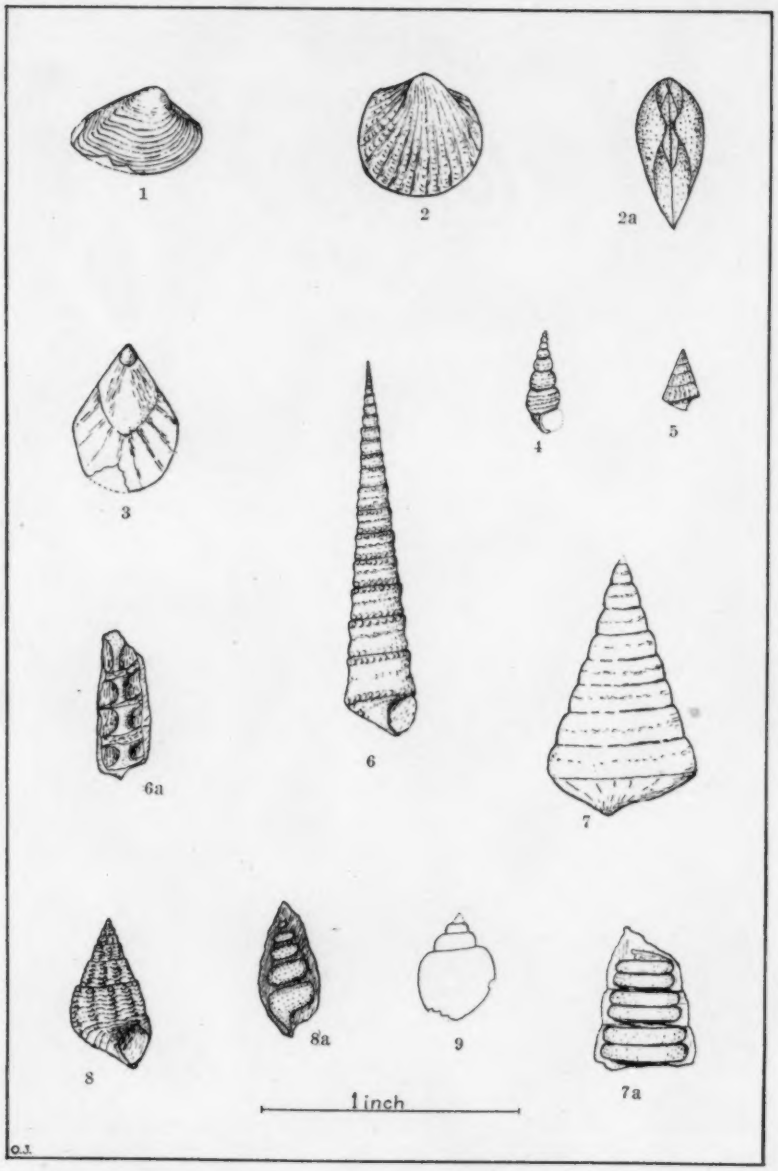
FIG. B. Granitic serrotes on the gneissic plain, Rio Grande do Norte. Photographs by G. A. Waring, 1911.



Fossiliferous Limestones one kilometer west of Itapasaroca, Rio Grande do Norte.

Fig. A. Looking east. The beds dip eastward about 5° into the plain.
Fig. B. Looking west. The beds are thrown into waves here.

Photographs by E. C. Starks, May, 1911.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2
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3
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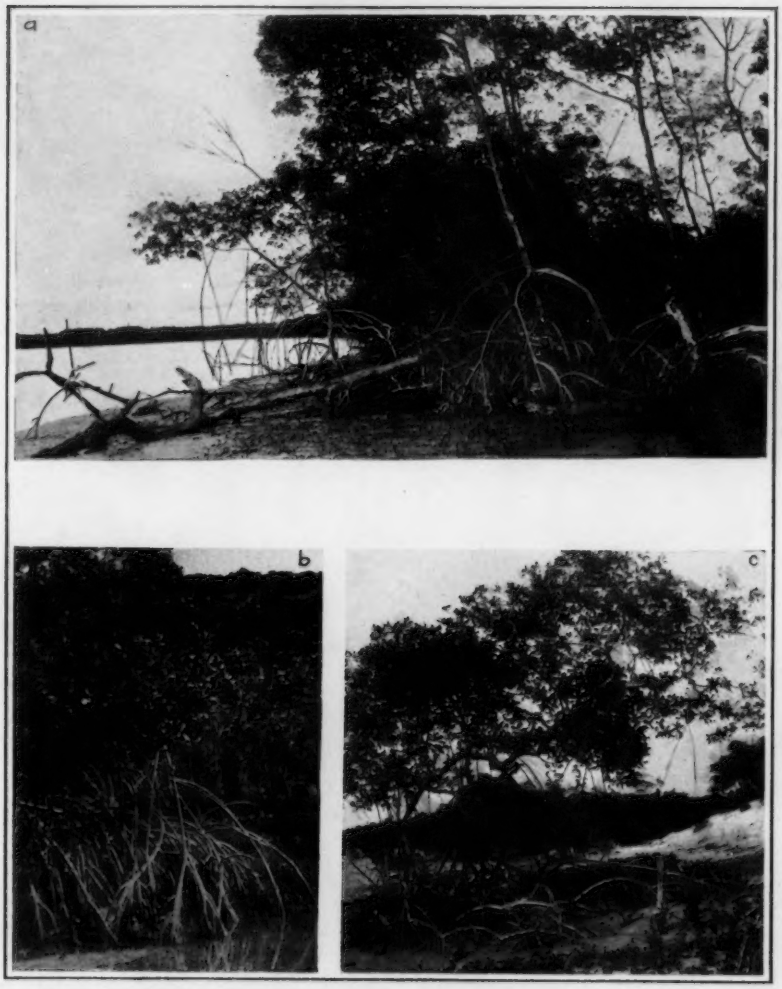
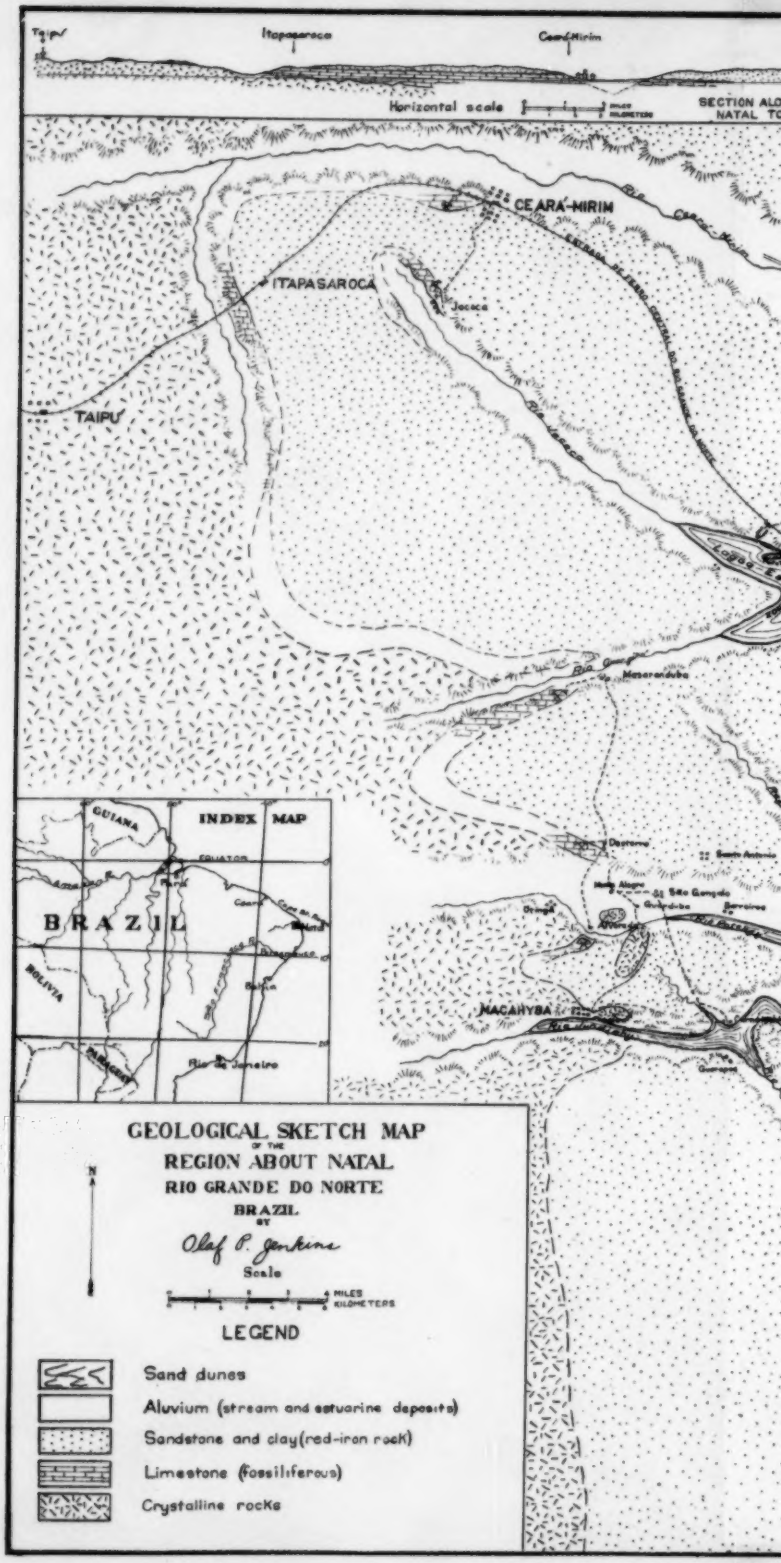
O.J.

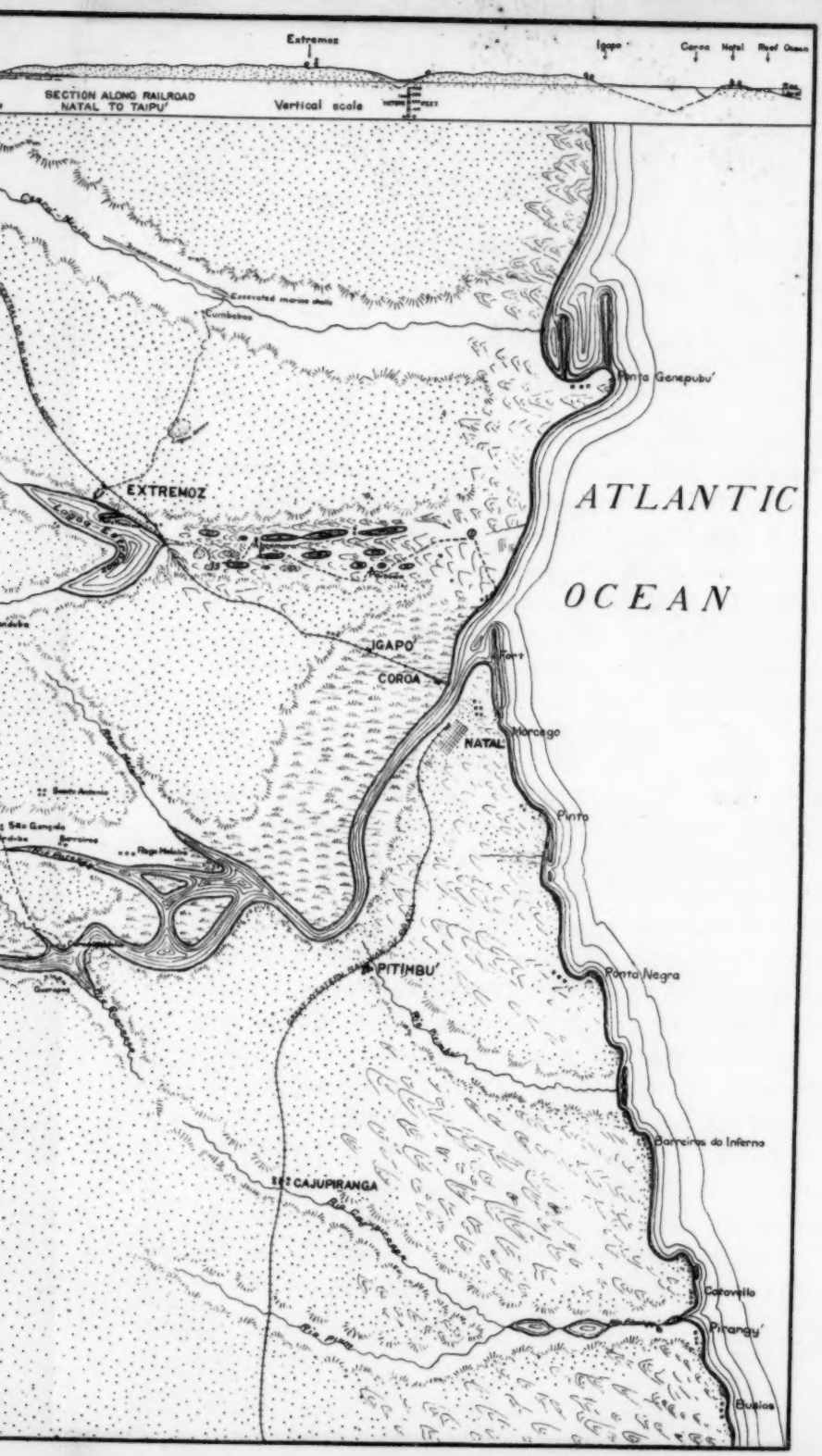


MANGROVE ROOTS, SILTING OF RIVER MOUTHS.

FIGS. A AND C. Mangrove roots at low tide, Tutoya, Maranhão. Photographs by G. A. Waring, 1911.

FIG. B. Mangrove roots at the mouth of Rio Pirangý, Rio Grande do Norte. Photograph by E. Leib, 1911.


Itapaseroca
Ceará Mirim
Horizontal scale
SECTION ALO
NATAL TO
CEARÁ-MIRIM
ITAPASAROCA
Jacoca
TAIPU
Rio Ceará Mirim
Rio Jacoca
Rio Guaraira Merim
Maracajaúba
Lagoa Es
Parnamirim
Santo Antonio
Lagoa Nova
São Gonçalo
Quintas
Barreiros
Rio Potengy
MACAHYBA
Guamaré
INDEX MAP
GUIANA
EQUATOR
BRAZIL
Pará
Ceará
Natal
Pernambuco
Bahia
BOLIVIA
PARAGUAY
Rio de Janeiro
GEOLOGICAL SKETCH MAP
OF THE
REGION ABOUT NATAL
RIO GRANDE DO NORTE
BRAZIL
BY
Olaf P. Jenkins
Scale
MILES
KILOMETERS
N
LEGEND
Sand dunes
Aluvium (stream and estuarine deposits)
Sandstone and clay(red-iron rock)
Limestone (fossiliferous)
Crystalline rocks


Extremoz
Igapo
Coroa
Natal
Reef
Ocean
SECTION ALONG RAILROAD
NATAL TO TAIPU'
Vertical scale
Excavated marine shells
Cumbaba
Ponta Genepubu'
ATLANTIC
OCEAN
EXTREMOZ
IGAPO'
COROA
Fort
Morcego
NATAL
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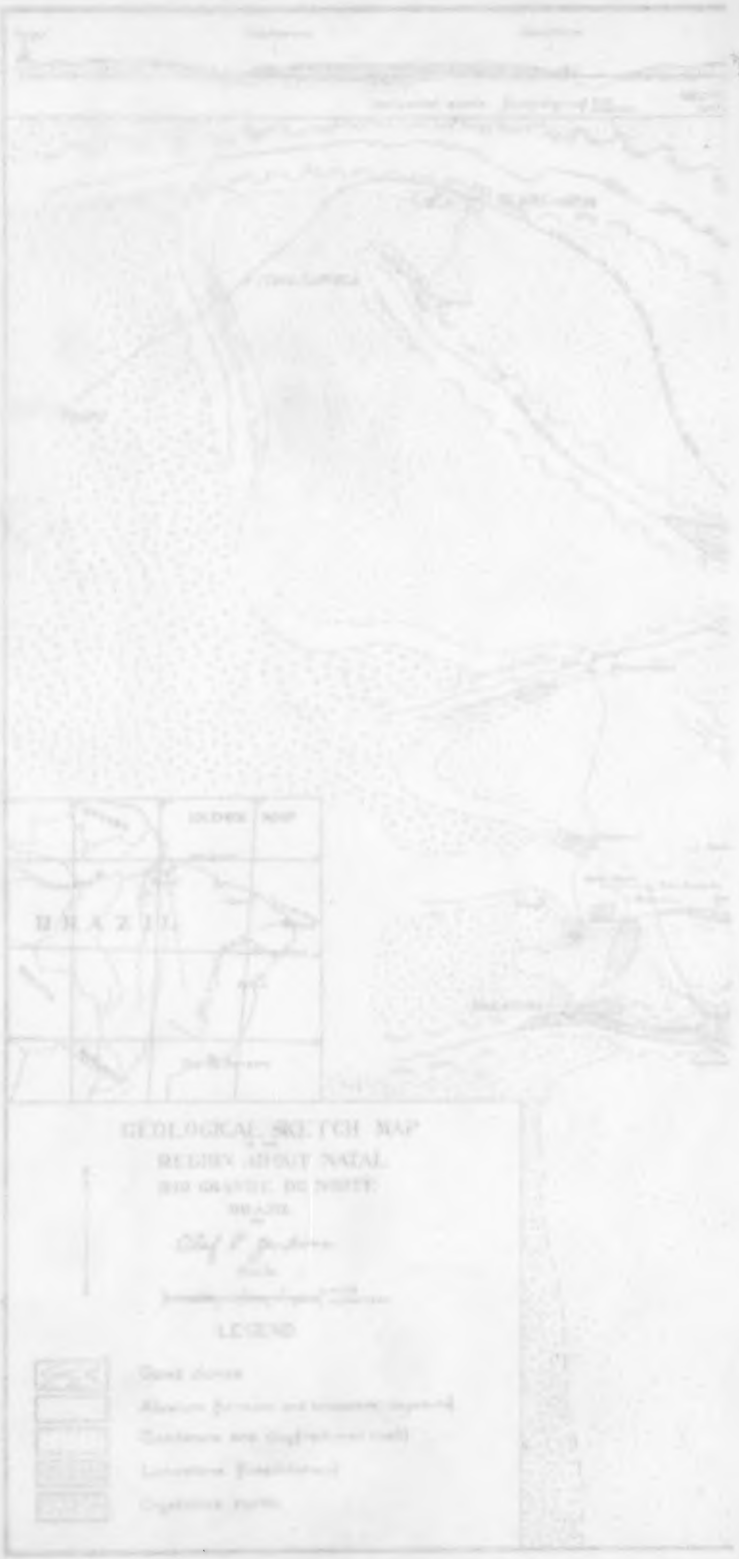
Ponta Negra
PITIMBU'
Barreiros do Inferno
CAJUPIRANGA
Caravilla
Pirangy'
Busios


BRAZIL
GEOLOGICAL SKETCH MAP
LEGEND

GUATEMALA AND THE HIGHEST NATIVE AMERICAN CIVILIZATION.

By ELLSWORTH HUNTINGTON.

(*Read April 18, 1913.*)

By common consent the most backward part of our continent is Central America. Among the republics of Central America Guatemala is considered to hold the lowest place. In Guatemala it is universally agreed that the province of Peten is the wildest, most uncivilized and most uninhabitable part. Peten, then, may be regarded as at the very bottom in the scale of American civilization. Its native inhabitants are either absolute savages, or semi-barbarians, densely ignorant and highly inefficient. Nevertheless in the past this region was the home of the highest civilization that ever developed in any part of the western hemisphere, a civilization which was not transitory, but lasted hundreds of years. It seems to have grown up where we find its traces, since nowhere else do we discover any premonitions of it. Here the ancient Mayas developed a unique system of architecture, whose earlier stages appear at Copan and the ruins of Peten, while its latest and most showy, although decadent, expression is found in the wonderful ruins of Yucatan a few hundred miles farther north. In this same part of Guatemala the Mayas devoloped the art of sculpture to such a point that their statues, though crude in many ways, represent the features of the ancient populace so exactly that type after type among the modern population is easily recognized in the monuments. Here the Mayas attained such skill in the mechanic arts that great stones fifteen to thirty feet long, and weighing 20 to 80 tons were transported from quarries a mile or two away and set up in the midst of great court-yards or temple areas. The buildings themselves were elaborately planned and decorated with all manner of carefully carved designs. All this was done with no tools, so far as can be

ascertained, except obsidian or flint. A greater achievement than this, however, was the construction of a calendar much more accurate than any known even in Europe until the introduction of the Gregorian calendar which we now employ. The construction of such a calendar must have demanded carefully written records for hundreds of years. This brings us to the greatest of the achievements of the Mayas. They had developed the art of writing in hieroglyphics, and apparently their type of hieroglyphics was higher than that of the Egyptians, for they seem to have been on the point of using specific symbols not to represent words but sounds, a step which even the Chinese have not yet taken.

From the point of view of the geographer, and perhaps of the historian also, the most remarkable feature of the civilization of the Mayas is that it developed in almost the worst physical environment to be found in any part of America. It might have developed in the healthful plateau of Guatemala where cultivation of the soil is easy, and where the population to-day is dense and relatively efficient, but instead of this it developed a hundred miles away in the fever stricken lowlands of Peten, where agriculture is extremely difficult and the population almost negligible. To-day for some unexplained reason the distribution of population and still more of culture in Guatemala is utterly different from what it was in the past. Perhaps nowhere else in the whole world have less than 2,000 years produced so profound a change, not only in the state of civilization as compared with other parts of the continent, but in the relative importance of different portions of the same small country no larger than the state of New York. The normal decay of races, the interplay of historic forces, the invasion of barbarians, the decadence due to luxury, vice and irreligion, the change of the center of world-power, or some of the other causes usually appealed to by historians may explain why the Maya civilization arose and why it fell. We may assume that it arose because it is the nature of a young and vigorous race to make progress, and that it fell because it is the nature of an old and exhausted civilization to decay. This, however, does not touch upon the problem which we propose to discuss in this paper. To-day the most progressive and energetic

people of Guatemala, its densest population, its greatest towns, its center of wealth, learning and culture, so far as these things exist, are all located in the relatively open, healthful, easily accessible and easily tillable highlands; in the past these same things were located in the most inaccessible, unhealthful, and untillable lowlands. Why the change?

Before we attempt to answer this question, it will he helpful to discuss the geographical provinces of Guatemala as they exist to-day, and as they were seen by the author during a recent visit, and to compare them with one another. From the point of view of present habitability Guatemala together with British Honduras, which is physically part of the same country, may be divided into three main belts dependent on vegetation,—(1) the Atlantic forest, (2) the central dry land, and (3) the Pacific forest. Each of these in turn may be divided into two parts. The plain of British Honduras in the north to a width of fifty miles, and the mountains of the southern part of that country and of eastern Guatemala to a distance of perhaps thirty miles from the coast form the first division of the Atlantic forest. Showers at all seasons either from the trade winds in our winter, or from the subequatorial area of low pressure in summer cause the land to be covered with a dense tropical forest, and to be infested with malignant types of malarial fevers. Only on the coast are there any real towns, and they exist chiefly by grace of the trade winds, which blow freshly from the ocean and drive away the mosquitoes. Strung along the beach under the cocoanut palms the low whitewashed houses of these towns make quite a show from the sea, but back of the first row there is often nothing but deadly swamp and mosquitoes. In the interior a few little villages sit in clearings by the brink of the somber rivers, and wait in sun or rain for precious mahogany logs to be hauled or floated out of the interior. Save for this, almost no one except an occasional gatherer of gum inhabits the dense forests. If the coast towns and the mahogany cutters be excluded the whole region cannot boast a population of much more than one person to every ten square miles, while even if the towns and woodcutters be included, British Honduras with an area of 7,500 square miles has only

42,000 people, or less than 6 to the square mile. The forests and fevers now keep mankind away, and apparently much the same was true in the past, for we find here only a few widely scattered ruins.

Inland from the coast strip there lies another section of the Atlantic forest, occupying most of the almost unexplored and semi-independent Guatemalan province of Peten, and extending south past the ruins of Quirigua towards those of Copan. In the north this Peten strip consists of a plain from which rise a few low ridges running east and west, and having a height of a thousand feet more or less. In the south it becomes mountainous. The vegetation is almost as dense as that of the coast strip except that in Peten considerable areas of grassy savanna prevail, thin pine forests grow in the sandy tracts known as "pine ridges," and on the westward edge and in other favored spots, among which Flores on L. Peten is the chief, the forest breaks down into jungle. The savannas appear to be due either to an excess of water often held near the surface by clayey hardpan, or to sand. The pine ridges, which are not ridges but merely slight swellings in the plain, are due to accumulations of sand. Neither in the past nor at present does it ever appear to have been possible to cultivate either the savanna or the pine ridges, but since the introduction of cattle by the Spaniards they have been utilized somewhat for pasturage. They possess not only the advantage of being fit for cattle-raising, but of being relatively healthful, and of being bordered by narrow strips of jungle wherein primitive agriculture is possible. The jungle regions on the immediate borders of the Peten strip contain a few villages, among which Copan is most worthy of mention. Aside from the limited areas of savannas, pine ridges, and jungle, the country is covered with forest, and is so feverish and so difficult to cultivate that its only inhabitants are mahogany cutters, gatherers of chicli gum, or raisers of bananas for export. All of these occupations, together with cattle-raising, are due entirely to the influence of modern European civilization, and had no place in the pre-Columbian period. The banana plantations have grown up within a few years and are practically all the work of the United Fruit Company, which employs four or five thousand people in the valley of the Motagua river.

Only some powerful stimulus, like the demand of the United States for fruit, could cause such plantations to arise. The strictest supervision is necessary in order that the bushes may be cut every three months, for in a year the native vegetation grows ten feet or so, and if left to itself would soon choke the banana plants. Still more unremitting vigilance is necessary to keep both the white men and the natives in health. From the wages of every employee, whether he receive fifty cents or fifty dollars per day, the Company takes two per cent. to pay for sanitary measures. Every plantation has its doctor and dispensary, and natives and foreigners are continually dosed with quinine. Yet even so, at certain seasons of the year, a single train may carry a score of staggering fever patients, the present hospitals are wholly inadequate, and in 1913 the company was erecting a new hospital at a cost of $125,000. Mr. Victor M. Cutter, manager of the Guatemala division of the United Fruit Company, states that about ninety per cent. of the people in his district, both natives and whites, suffer from malaria and its sequelæ. In spite of all precautions about twenty per cent. have the fever in a serious form.

In the entire Peten strip of the Atlantic forest, from Copan on the south up through Quirigua, the lake of Izobal and the province of Peten, it is probable that the total population does not exceed 20,000 in an area of nearly 15,000 square miles. If the cattle-raisers, mahogany cutters, gum gatherers, and banana raisers be excluded, and if we include only the people who procure a living in ways possible before the coming of the white man, the population is reduced to probably less than ten per cent. of the figures given, or only one person for seven square miles. Of course these figures are a mere approximation; there is no such thing as a census, for much of the country is still unexplored, and the wild Indian tribes practically ignore the Guatemalan supremacy. For day after day, however, the traveler finds no inhabitants, and place after place which appears on the map as a village proves to have only two or three houses or to be merely an abandoned hut. Roads and even trails are almost non-existent, and in most places the machete must constantly be used to open up a pathway. Mr. Frank Blanceneaux,

who for six or seven years spent a large part of his time in traveling through Peten in search of mahogany, probably knows that province as thoroughly as any one. He thinks that the population does not exceed 10,000, and that at least 95 per cent. of it consists of cattle raisers, mahogany cutters and gum gatherers. Nowhere has he seen a village of more than a hut or two in the genuine forest, and nowhere do people practice any real agriculture in the forest as opposed to the jungle. South of Peten, along the line of the railroad from Puerto Barrios to Guatemala, for sixty miles from the Atlantic coast until one comes to the poor little village of Los Amates, there would not be a single inhabited place were it not for the railway itself and the banana plantations of the United Fruit Company. Los Amates lies on the edge of the forest where it breaks down into big jungle.

Whatever may be the exact figures as to population it is evident that heavy rains, dense vegetation, and malignant fevers to-day render the Peten strip of the Atlantic forest almost uninhabitable. Yet in the past this was by no means the case. Practically all of the great Maya ruins outside of Yucatan lie in this strip or in its northern and northwestern continuation in the Mexican provinces of Chiapas, Tabasco and Campeche. Copan, one of the most remarkable of the ancient cities, lies on its edge, although not actually in it; Quirigua lies within it, although only a few miles from the border; and Seibal, Tikal, and a score of others as far as Palenque in the north, lie well within its dense jungle and forests. These places were obviously towns of importance, such as grow up in interior, agricultural districts far from important lines of communication only when there is a considerable population round about. How dense the former population may have been we cannot estimate, for the cover of vegetation is so thick that we have no idea of the exact number of ruins. It is scarcely an exaggeration, however, to say that for every family now supported by ordinary agriculture, there was probably a village or hamlet, in the days of the Mayas, and for every modern village a city.

Turning now to the relatively dry portion of Guatemala, the second of our three divisions, we find it divided into arid bush

country, lying in low, isolated valleys or basins such as Zacapa, and highlands where pine or temperate forests prevail. The bush country is unimportant, being of small area. In some places it is so hot and dry that cacti and mesquite bushes make it look like the lowlands of Arizona. It is fairly well inhabited and moderately healthful. The people are in advance of the poor denizens of the forest zone but are miserably inefficient, idle, weak-willed, and immoral. The real strength of Guatemala is in the highlands, where the vegetation takes on an aspect suggestive of the temperate zone. There, on the plateau amid pine-clad hills at an altitude of 4,000 to 8,000 feet, all the large towns are now located. The conditions of health, from a tropical point of view, are everywhere good. Typhus, dysentery and other disorders, to be sure, often sweep the country; and faces pitted by smallpox are frequently seen. These diseases, however, although causing a high death rate, are temporary. Their ravages are as nothing compared with those of the deadly malarial fevers which in the lowland forests return season after season to blight and destroy the same places and the same people. From the coast upward, according to universal testimony, the health, energy, industry, and thrift of the native Guatemalans in general show an increase. It seems a curious reversal of what we are wont to call normal conditions, when one sees rich, fertile plains along the coast almost uninhabited, then finds the population fairly dense on steeply sloping, stony mountain sides at altitudes of three to five thousand feet, and finally on the hilly plateau at 8,000 feet sees little thatched houses clustering thickly everywhere, and every available bit of land almost as carefully and industriously cultivated as in China. Even more curious, perhaps, is the fact that here where the population is now so dense there are relatively few important ruins and none of the advanced type found in Peten. There is no reason to think that ruins which once existed have disappeared to any greater extent than has happened in Egypt, Syria, Greece, Rome, or any other country where a high civilization in the past has been followed by a dense population at present. Moreover ruins of a certain kind are found in considerable numbers, but they are insignificant and probably of late date compared with those of Peten. The carved

stones which one sees, for example, at Guarda Viejo near Guatemala City are small, crudely executed, and inartistic, utterly different from the clean-cut, highly complex and truly artistic stelæ of enormous size at Quirigua. The plain, almost unadorned structures at Quiché, the greatest ruins on the plateau, bear to the highly developed groups of buildings and monuments at Copan about the same relation that modern Guatemalan churches bear to St. Peter's at Rome. In the days of the Mayas the highlands may have been as densely populated as to-day, although we have no positive proof of this, but instead of being the center of the life and activity of the country they were a provincial outpost.

The southwestern side of the high plateau of Guatemala is bordered by a line of splendid volcanoes at the foot of which towards the Pacific Ocean there lies a narrow plain. This plain, together with the lower slopes of the mountains, forms the third of our three divisions of Guatemala from the point of view of habitability. From a height of 4,000 feet down to about 500 the slopes of the mountains and the inner edge of the plain are covered with dense vegetation. At an altitude of approximately 2,000 to 3,000 feet, the vegetation attains the dignity of real tropical forest with mahogany trees, tree ferns and the like, while on either side it assumes the form of forest-like jungle merging gradually into pine forest toward the uplands and low jungle and bush toward the coast. All except the upper mountainous part of the region is malarial and unhealthful; although not so bad as the Atlantic forest because the drainage is better. The strip of real forest would to-day be practically uninhabited were it not that the demands of the modern civilized world have led to the cultivation of coffee, chiefly by German companies with Indian labor brought from the highlands. Lower down, on the edge of the plain, there would be a small population even without the impetus of coffee. A few little towns like Retalhuleu, Santa Lucia, and Escuintla date back many centuries. They are notoriously unhealthful, however; their inhabitants are universally pronounced inefficient and apathetic; and their population of from 2,000 to 10,000 people is only 10–20 per cent. as large as that of corresponding towns on the plateau. Yet, here, curiously enough, we

again find abundant traces of an ancient race of relatively high culture. The ruins are by no means equal to those of the Peten strip, and there appear to be few hieroglyphics. Nevertheless they belong to the same civilization although to a later stage subject to foreign, that is Nahua, influence. At places like Baul and Pantaleon great blocks of hard basalt have been found carved with scenes of sacrifice, or chiseled to represent gigantic faces whose peculiar types of slit nostril, high cheek, or projecting mouth can still be recognized in individual Indians.

The seaward portion of the Pacific belt needs little further comment. Beginning with jungle where the modern towns and ancient ruins come to an end, its shoreward portion is covered with dense, low bushes among which short bamboos are often conspicuous. Although dry and parched in the winter season, much of it becomes a vast swamp when the rains swell the mountain streams and cause them to spread out over its flat expanses. Mosquitoes then abound causing fevers which are often of the "pernicious" type accompanied by hemorrhages of blood producing immediate death. Practically the only inhabitants are a few cattle raisers, who are described as the lowest of the low. In the past, conditions were apparently no better, for we find no trace of ruins here.

Before we consider the possible causes of the contrast between the past and present, it will perhaps add to the clarity of our ideas if our six belts are arranged in tabular form.

It is worth while to emphasize the strange contrast between past and present. The belts immediately along the Atlantic and Pacific coasts may be left out of account, since in the past, just as at present, they appear to have been too forested and too feverish for human occupation to any great extent. To-day the other four divisions stand in the following order so far as progress, achievement, and density of population are concerned; first the highlands, second the dry valleys, third the coffee belt, fourth the Peten strip. In the past the ruins tell a very different tale,—the Peten strip stood first, then the coffee belt and the dry valleys, and last of all the highlands, the reverse of the present order. To-day, in Central America, the physical conditions under which mankind tends most to increase in

	Nature of Vegetation.	Health Conditions.	Condition of Agriculture.	Present Density of Pop.	Condition of Population.	Abundance and Condition of Ruins.
1. Atlantic coast	Dense forest	Very unhealthful	Very difficult	Very scanty	Degraded	Very few so far as known but of fairly high type
2. Peten belt	Dense forest with some savannas and jungle	Very unhealthful	Very difficult	Very scanty	Degraded	Numerous and indicating the highest native American culture
3. Dry valleys	Bush or low jungle	Fairly healthful	Fairly easy	Moderately dense	Low, but well ahead of 1, 2, and 6	Moderately numerous and of fairly high type
4. Highlands	Pine forest	Healthful	Easy	Very dense	By far the best in Guatemala	Quite numerous, but mostly of rather low type, that is, provincial or degenerate
5. Pacific coffee belt	Forest and jungle	Unhealthful	Fairly difficult	Rather scanty	Low, but ahead of 1, 2, and 6	Moderately numerous and of fairly high type
6. Pacific coast	Bush	Very unhealthful	Difficult	Very scanty	Degraded	None so far as known

numbers and to progress in culture appear to be high altitude, good drainage, and a fairly long, dry season. Altitude in itself, however, does not appear to be essential, for the low dry plain of northern Yucatan seems as well off as the highlands of Guatemala. Perhaps the exposure of that part of Yucatan to the ocean and to strong winds from the north produces the same effect as elevation. Opposed to these favorable conditions stand those which conspire to hold man back and keep him in a low stage of civilization. Omitting low altitude, which is important merely because of its effect on other factors, we are confronted by four chief conditions,—first, the prevalence of fevers; second, the prevalence of great heat and moisture almost without change from season to season; third, the difficulty of carrying on permanent, intensive agriculture and fourth, the relative ease of getting a living in the jungle.

Little by little the world is learning that the most dangerous diseases are not necessarily those which show the highest deathrate.

The plagues of the Middle Ages loom large in history, but they did not do a tithe as much harm as syphilis. Yellow and typhus fevers may decimate a population, but they are far preferable to the slow, irresistible ravages of recurrent malarial fevers which rarely seem to kill, but merely undermine the constitution, leaving both mind and body inefficient. Tuberculosis, in our own land, is so dreaded that we wage a crusade against it, but its dangers are probably far less than those of the insidious colds which year after year attack fully half of our northern populations, not killing them, not even doing more than spoil their work for a few days, and yet in the aggregate causing an incalculable amount of damage and giving an opening for a large part of our cases of consumption, diphtheria, deafness, and many other afflictions. Just as we, in our huge folly, long neglected consumption and still largely neglect the even more insidious ordinary colds, so the man within the tropics often ignores malaria. Again and again I have talked with people who said there was no fever in the particular place where they lived or that they had not had fever, but before the next meal they took a dose of quinine, and that same night, perhaps, they reeled with a touch of fever or shivered with a chill. They called it "nothing," but even quinine did not prevent them from being weakened by it. Few foreigners, especially children, can live long in the lowlands under ordinary conditions without being affected.

As for the natives, it is often stated that they become immune to fevers, but here is what Sir Ronald Ross, one of the chief authorities on the subject, has to say:

"These diseases do no affect only immigrant Europeans, they are almost equally disastrous to the natives, and tend to keep down their numbers to such a low figure that the survivors can subsist only in a barbaric state. To believe this one has to see a village in Africa or India full of malaria, kala-azar, or sleeping sickness, or a town under the pestilence of cholera or plague. Nothing has been more carefully studied of recent years than the existence of malaria amongst indigenous populations. It often affects every one of the children, probably kills a large proportion of the newborn infants, and renders the survivors ill for years. Here in Europe nearly all our children suffer from certain diseases—measles, scarlatina, and so on. But these maladies are short and slight compared with the enduring infection of malaria. When I was studying malaria in Greece in 1906 I was struck with the impos-

sibility of conceiving that the people who are now intensely inflicted with malaria could be like the ancient Greeks who did so much for the world; and I therefore suggested the hypothesis that malaria could only have entered Greece at about the time of the great Persian wars—a hypothesis which has been very carefully studied by Mr. W. H. S. Jones. One can scarcely imagine that the physically fine race and the magnificent athletes figured in Greek sculpture could ever have spent a malarious and spleno-megalous childhood. And conversely, it is difficult to imagine that many of the malarious natives in the tropics will ever rise to any great height of civilization while that disease endures amongst them. I am aware that Africa has produced some magnificent races, such as those of the Zulus and the Masai, but I have heard that the countries inhabited by them are not nearly so disease-ridden as many of the larger tracts. At all events whatever may be the effect of a malarious childhood upon the physique of adult life, its effects on the mental development must certainly be very bad, while the disease always paralyses the material prosperity of the country where it exists in an intense form.

"Consider now the effects of yellow fever, that great disease of tropical America. The Liverpool School sent four investigators to study it, and all these four were attacked within a short time. One died, one was extremely ill, and two suffered severely. The same thing tended to happen to all visitors in those countries. They were almost certain of being attacked by yellow fever, and the chances of death were one to four. Tropical America was therefore scarcely a suitable place for a picnic party! But malaria and yellow fever are only some of the more important tropical diseases. Perhaps the greatest enemy of all is dysentery, which in the old days massacred thousands of white men, and millions of natives in India, America, and all hot countries, and rendered survivors ill for years. Malaria has always been the bane of Africa and India; the Bilharzia parasite of Egypt; and we are acquainted with the ravages of kala-azar and sleeping sickness. Apart from these more general or fatal maladies, life tends to be rendered unhealthy by other parasites and by innumerable small maladies, such as dengue and sand-fly fever, filariasis, tropical skin diseases and other maladies, . . . True, we have many maladies in Europe, but in order to compare the two sets of diseases we should compare the death-rates. Whereas in England it is a long way below 20 per thousand per annum, throughout the tropics it is nearer 40 per thousand. In India alone malaria kills over a million persons a year, and dysentery and malaria kills many hundreds of thousands. I have seen places in which the ordinary death-rate remains at between 50 and 60 per thousand; others which were so unhealthy that they were being deserted by their inhabitants; and others, lastly, which were simply uninhabitable. What would people say if such a state of things were to exist in most villages in England, Scotland, and Ireland?"[1]

On the whole it seems safe to say that in tropical countries the

[1] *United Empire*, February, 1913, pp. 123–124. Sir Ronald Ross, "Medical Science and the Tropics."

density of population and the stage of culture depend to a large extent upon the amount and kind of fevers. Yet fevers are far from being the whole story. Few who have ever been in the torrid zone will deny that under prolonged and unvarying conditions of heat and dampness both physical and mental energy decline. One is tempted to sit down idly and rest and enjoy the warm air. When it is time for a new piece of work one tends to hesitate and to be uncertain as to just how to begin. Of course there are exceptions, and of course a long inheritance of activity in cooler regions will for years largely overcome these tendencies. Nevertheless of the scores of northerners, both American and Europeans, whom I have questioned in the torrid zone there was scarcely one who did not say that he worked less than at home. At first a considerable number said that they had as much energy as at home, but then they added that it was not necessary to work so hard, and moreover that they did not feel like it. Much more striking was the absolute unanimity with which they said that when they experienced a change of climate, especially if they went from lowlands to highlands, or still more when they returned to the north, they at once felt an access of energy which lasted some time after their return. To a New Englander accustomed to look upon our southern states as having a warm, debilitating climate, it is interesting to hear people in Guatemala speak of being stimulated as soon as they feel the cool winter air of New Orleans. The natives of the torrid zone are of course so accustomed to the heat that they enjoy it and suffer from even a slight degree of cold, but the very fact of being wonted to the heat seems to carry with it the necessity of working and thinking slowly. The universality with which this is recognized in Central America is significant. Again and again, when one asks about labor conditions in specific places, one is told, "Oh yes, the people there are all right, but you know it's always hot down there and they don't work much." All this, I know, is perfectly familiar, but it deserves emphasis because the great ruins are practically all in the hot country where "they don't work much."

In addition to debilitating fevers and an enervating uniformity of warm, moist atmospheric conditions, tropical countries suffer from

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peculiar agricultural conditions. In the great forest such as that of Peten, where rain falls at all seasons, the making of clearings is practically impossible. In the dense jungle, such as that at an elevation of one to two thousand feet in the Pacific coffee belt of Guatemala, this is usually but not always possible. It depends on the length and character of the dry season in February, March, and April. Two or three weeks of steady sunshine are said to suffice to prepare the cut bushes and smaller branches of the trees for burning, but sometimes there is scarcely a rainless week during the whole year. This happened in 1913. People, who chanced to do their cutting early, burned their fields and were able to plant a corn crop, but many cut too late and failed. It is easy to say that everyone ought to cut and burn early, but in the first place the lethargy of the torrid zone leads people to put things off till the last moment. In the second place, if the land is burned over too early, weeds and bushes will sprout and grow to a height of a foot or two before it is time to plant the corn. Hence a second clearing will be necessary, and if a second burning is impossible the corn will be at a disadvantage.

This does not end the difficulties of agriculture in the dense jungle. Thanks to the abundant vegetation and constant rains or to the hot sun which causes rapid decomposition, or to some other unknown cause, many important chemical ingredients are quickly leached from the soil. Hence while the first corn crop is usually very abundant, the second, if it follows immediately after the first, is poor, so poor that it is scarcely worth raising. The regular custom is to cultivate a given tract one year, let the bushes grow four years, till they are perhaps fifteen or twenty feet high, and in the fifth year cut, burn, and plant again. Thus agriculture in the dense jungle is not only precarious, but it is forced to be extensive and superficial rather than intensive and careful. Therefore it does little to stimulate progress. In the drier regions, whether high or low, the soil is not so quickly exhausted, especially if the absence of roots or other conditions make it possible to turn up new soil by ploughing or otherwise. The crops are by no means so abundant as in the wetter places, but the same land can be cultivated year after year

with only short periods of rest. The cultivator must work harder than in the wet places, but his success is less precarious, the efforts of one year have a direct bearing on succeeding years, and permanent industry in encouraged.

Still another disadvantage of the low, wet regions needs to be briefly discussed. It is hard for mankind to get a living under any circumstances in the genuine tropical forest, and he must work at least moderately for one in the dry parts of tropical lands. In the big jungle, however, game is abundant, wild fruits ripen at almost all seasons, a few banana plants, palm trees, and yams will almost support a family, and if a corn crop is obtained at all, the return is large in proportion to the labor. Thus, so long as the population is not too dense, life is easy and there is little stimulus to effort. Under such conditions the density of population is not likely to increase, for only by a revolutionary access of skill and industry would it be possible to change from the easy, hand to mouth life of the present to the intensive, industrious life which would be necessary in order to support a dense population.

Thus far we have seen that the distribution of population in Guatemala to-day is unquestionably very different from what it was in the past. We have further seen that the physical conditions which make for density of population and increase of civilization are distributed in a peculiar fashion. They prevail in the highlands where there is no evidence that the civilization of the past was any higher than that of the present; and do not prevail in the lowlands where there is the clearest and most abundant evidence of the prevalence for many centuries of a civilization far in advance of that of to-day. Moreover the ancient civilization did not come to the country full-fledged as did that of Spain in later times. It did not do its finest work at once and then decline as did that of the Spaniards after they had built their massive old churches. On the contrary it apparently arose where we find its ruins, and it endured for centuries before it decayed. The most fundamental fact is not the great change which has taken place in the character of the Maya race. Nor is it the fall of Maya civilization, whether from internal decay or external attack. It is merely the simple fact that the

highest native American civilization grew up in one of the worst physical environments of the whole western hemisphere. Close at hand, in the Guatemalan highlands on one side, and in the dry strip of northern Yucatan on the other, far more favorable environments were occupied by closely allied branches of the same race, but the greatest civilization grew up in the densely forested, highly feverish, and almost untillable lowlands of Peten and eastern Guatemala.

The explanation of this peculiar state of affairs appears to lie in one or all of three things; first, the character of the Maya race; second, the relative abundance and virulence of various diseases; and third, the nature of the climate and its effect on forests, diseases, and agriculture. It is possible to adopt the usual unexpressed assumption of historians and to suppose that the original Mayas were stronger and more virile than any other race which has entered the torrid zone, and that because of some unexplained stimulus whose nature it is hard to surmise they flourished greatly for many centuries in a habitat in which modern races can barely subsist. The theory that the Mayas were different from other races has a good deal to commend it. They certainly were a remarkable people. The only question is how remarkable. The nearest analogue to their achievements is found in the ruins of Indo-China, Java, and Ceylon. In none of these cases, however, was the degree of success anything like so great as among the Mayas. The Asiatic races appear to have been like the Spaniards, invaders who did not develop a new civilization but brought their ideas with them from other places where we can still see remains of the parent culture. Moreover they did not rise to the height of inventing a method of writing, and, in Indo-China and Java at least, they appear to have had the advantage of tools of iron. Nevertheless, when their history is finally understood, we shall perhaps find that their civilization and that of the Mayas arose under similar conditions because of similar causes. This, however, is aside from the question. The important point is that no matter how capable we suppose the ancient Cingalese, Indo-Chinese, and Javanese to have been, the ancient Mayas were far more capable, for not only were the achieve-

ments of the Mayas greater than those of the others, but their opportunities were less. Hence, if we explain the rise of Maya culture solely on the basis of racial character we are forced to assume that the ancient Mayas were not only almost immeasurably in advance of any race that now lives under a similar environment, but were far more competent than any other race that has ever lived permanently in any part of the torrid zone. Indeed in their achievements in overcoming an adverse environment, we are perhaps obliged to put them on a pinnacle above any other race that has ever lived.

Without denying that the Mayas were a remarkable people, let us entertain the further hypothesis that in the days of their greatness tropical fevers either had not been introduced into America, or were by no means so virulent as now. This helps us greatly, for it relieves us of the necessity of assuming the Mayas to have possessed a degree of resistance to fevers far in excss of anything known to-day. There are, however, grave objections to this hypothesis. In the first place it is a pure assumption entirely unsupported by any independent evidence. In the second place, tropical diseases are numerous, and even malarial fevers are of several kinds. We may readily suppose that one or two diseases may have been introduced into Central America between the time of the Maya civilization and the Spanish Conquest, but in the entire absence of any evidence it is a rather large assumption to suppose that many diseases were thus introduced and that they were able to work so great a revolution. Thirdly, this hypothesis does not explain why the advancement of civilization went on so rapidly and for so long in spite of the enervating effects of almost unchanging heat and dampness. Nor does it explain why the Maya civilization reached the coast at only one or two spots. So far as topography is concerned there is nothing to prevent this on either coast. Much of the narrow Pacific plain could be cultivated with ease even though swamps do cover part of it, and on the Atlantic side the parts of the forest where there are no ruins seem to be no worse than those where they exist. The native inhabitants of this region all appear to have been of Maya stock, even though they may not have be-

longed to the main branch. Under such circumstances it hardly seems as if so progressive a civilization could have existed many centuries without extending its influence to the coast in British Honduras, unless there had been some preventive such as fever.

The assumption that in Central America tropical diseases were formerly less abundant or less baneful than now relieves us of the necessity of supposing that the Mayas, remarkable as they were, possessed a degree of immunity or resistance to disease far in excess of that of other races, but it does not relieve us of other difficulties. Moreover as it now stands it has the weakness of being a pure assumption with no assignable cause and no independent evidence. In order fully to explain the location of so high a civilization in Peten rather than in the highlands of Guatemala it seems necessary to supplement our assumptions as to the character of the Mayas and as to the prevalence of disease by the further assumption of a change of climate. The sort of change which would accomplish the required result would demand that at the height of Maya civilization climatic conditions should have been such that the forests of Peten would not be so dense as now, and hence that mosquitoes of the anopheles family would not be so abundant. In other words it would demand conditions like those which prevail to-day two hundred and fifty to three hundred miles north of Guatemala in the northern part of the peninsula of Yucatan. There the climate is to-day such that low jungle takes the place of dense forests. Mosquitoes of the anopheles species are rare. Malaria is comparatively unimportant. Thanks to these conditions the country is one of the most prosperous and progressive to be found anywhere within the tropics at sea-level. These favorable conditions are due to the fact that although heavy equatorial rains fall in summer and make the country fruitful, there is a long dry season during the winter and spring. If such conditions were to spread two hundred or three hundred miles southward into Peten that region would greatly change its character. Agriculture would still be subject to some handicaps, but would be nothing like so difficult and haphazard as at present. The areas of big jungle where life is excessively easy so long as the population is scanty, but where intensive agriculture

is to-day difficult would be reduced. Debilitating malarial fevers would prevail but little under such conditions, and the fact that Peten is a lowland, fertile and easily accessible, would make it a natural center of civilization. In other words if we adopt a climatic hypothesis of the kind here outlined, it does not lead us to abandon our other hypotheses as to the racial character of the Mayas, or as to the debilitating effects of disease. It simply supplies the elements which the other hypotheses lack.

The hypothesis of a change of climate in Guatemala by no means finds its only support in the considerations just set forth. On the contrary two independent lines of reasoning lead to the same conclusion. One of these is the existence of alluvial terraces in close connection with the ruins of Copan, and the other is the logical result of the investigation of ruins, lakes, and deserts in Asia, and of similar phenomena together with the growth of trees in North America. Both must be dismissed briefly. During the Pumpelly expedition sent out by the Carnegie Institution of Washington to Central Asia in 1903, Professor William M. Davis and the writer investigated a large number of alluvial terraces in mountain valleys from Persia eastward to Chinese Turkestan. From various lines of evidence set forth in the report[2] of that expedition they came to the conclusion that the terraces must be due to variations of climate. Otherwise they could scarcely occur with such a wide and regular distribution, and with such a minute adaptation to every valley no matter which way it sloped or how large it might be. Further study in the drier parts of the United States and northern Mexico as well as in Greece and Turkey seems to confirm this idea. It has been found, furthermore, that terraces of the same kind and apparently of the same climatic origin extend down into Southern Mexico and are well developed in the state of Oaxaca. In Guatemala the Motagua and other rivers are characterized by similar terraces which are described in full in the author's forthcoming volume on the "Climatic Factor" to be published shortly by the Carnegie Institution of Washington. It must suffice to say here that the famous

[2] "Explorations in Turkestan," Vol. 1, 1905, Carnegie Institution of Washington, Publication No. 26.

ruins of Maya culture lie upon a terrace of exactly this sort, while below the ruins there lies another similar terrace formed since the ruins were built. This seems to indicate that since the foundation of Copan, probably early in the Christian era, there has been a double climatic change whereby the Copan River, after having filled up its valley to the level of the upper terrace, was then impelled, first, to carry away material from the valley bottom, next to deposit new material, and again to carry it away. In other words the terraces seem to afford independent evidence that since the building of Copan the climate of Guatemala has been subject to distinct pulsations.

The other line of evidence is so complex that only the results can here be stated. From a prolonged study of ruins in dry places, roads and deserts which are now impassable, traces of springs where no springs now exist, elevated strands of enclosed salt lakes, and other lines of historic, archæological and physiographic evidences the writer has been led to believe that in central and western Asia, Greece, north Africa and perhaps elsewhere climatic pulsations have taken place during historic times. A study of similar lines of evidence in the United States under the auspices of the Carnegie Institution in the years 1910–1912 led to a similar conclusion here. Finally still another independent line of research was adopted, namely the measurement of the rate of growth of the giant sequoia trees of California which grow in a region where the thickness of the rings depends largely upon the amount of rainfall. This led to the same conclusion, namely that pulsatory changes of climate have taken place to a marked degree during the past three thousand years. The nature of the change has been inferred from various sources, especially from a comparative study of the meteorological records during years when the trees of California grew rapidly or slowly during the last half century. From this it appears that moist periods in regions like Persia, Greece or Arizona are probably due to the fact that the cyclonic storms of winter not only move farther south than usual and hence are uncommonly frequent in those countries but perhaps begin earlier in the fall and last longer in the spring. This, of course, reduces the length of the dry season in summer.

Farther south in the torrid zone, however, the effect would appear to be the exact opposite. That is, if the belt of cyclonic storms is pushed equatorward in winter it would seem to mean that the belt of sub-tropical high pressure and drought whence the trade winds take their rise is also pushed equatorward. Thus during the winter the dry conditions of the semi-arid or desert belt which encircles the earth at about latitude 25° to 30° would be pushed farther toward the equator. The result of this would seem to be to force the trade winds so far south during winter that they would not have their present effect in causing rainfall throughout practically the whole winter in Peten. On the contrary, there would be a dry season of several months duration such as now prevails in Yucatan and in the Guatemalan Highlands. This would prevent the growth of forests and cause them to be replaced by jungle or bush. Here again, then, a third line of evidence appears to point to a pulsatory climatic change which would produce results in accordance with our first assumption.

Here we must let the matter rest. The theory of changes of climate involves so many historic and economic consequences that it demands most careful consideration. Perhaps it is possible to explain the peculiar location of the ancient Maya civilization on some other hypothesis, but thus far no other seems to be supported by so much independent evidence. The acceptance of the climatic theory does not oblige us to change our ideas as to the remarkable character of the Mayas, or as to the causes of the development of civilization. It merely provides conditions under which it becomes probable rather than merely possible that a race might have developed. In other words it removes the great difficulties of agriculture. It provides a habitat which to a certain extent would be more free than at present from the debilitating influences of heat and moisture; and it does away with the conditions that now cause such terrible fevers. In all these ways, then, while it does not conflict with accepted ideas as to the historic development of civilization, it removes some of the difficulties in the way of accepting those ideas.

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THE CORRELATION OF STRUCTURE AND FUNCTION IN THE DEVELOPMENT OF THE NERVOUS SYSTEM.

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(*Read April 18, 1913.*)

Catch phrases sometimes creep into scientific literature where their presence may be as insidiously suggestive of the possession of imaginary stores of knowledge as they are when employed in the description of current events. We have for example become so accustomed to affirming the history of the individual reproduces in miniature the history of the race that we are often in danger of assuming a greater degree of familiarity with the details of ontogenesis than is warranted by a careful survey of the facts. Our knowledge of the primitive reactions of the higher organisms in relation to synchronous structural conditions is still so meagre that it has scarcely risen above the stage of conjecture and cannot be presented in the form of organized experience. Although it is not necessary to actually question the validity of a very useful hypothesis, based upon the similarity of the more striking features in ontogeny that are paralleled by the chief events of phylogenetic development, there is nevertheless adequate reason for emphasizing the necessity not only for more careful study of the correlation of events in the structural and functional growth of the higher organisms, as fundamental to a more comprehensive understanding of the nature of nervous reactions, but also as a method of determining the factors of individual behavior.

Efforts have already been made by a few investigators to try and study the relationships existing between the structural conditions existing at certain epochs, and the character of the synchronous responses of the embryo. The observations of Wintrebert, probably among the first to be recorded in the discussion of these special problems, were not by any means as extensive or as carefully planned

as the work carried on by Coghill, which will unquestionably form a basis for future studies of importance.[1] Some of the results of my own observations along these lines have been referred to in three papers.[2]

Before attempting to continue the description of the details of my own investigations I wish to call attention to the variety as well as importance of the problems awaiting solution in this special field of enquiry. Many problems of phylogeny naturally suggest the consideration of questions relating to the correlation of structure and function. We find a parallel for the succession of events in racial development in the ontogenetic sequence or the life-history of the individual, in which are revealed a chain of phenomena much better adapted for detailed study than those occurring in the former and, what is of still greater importance, is that the latter are to a certain extent under the control of the investigator. The comparative rapidity with which individuals pass through the various stages in development is also a factor facilitating enquiry.

What is particularly needed at present is a careful systematic study of the initial responses in the lives of embryos, representing several different species of animals, and a record of these phenomena which is sufficiently detailed to indicate the relationship existing between the physiological events and the changes taking place within the nervous system. Unfortunately investigators have long been hampered by the compelling desire to attempt to solve the problems relating to the complex nervous system of the adult before considering the simpler correlations possible in the early life of the embryo.

Among the primitive adjustments of all organisms those for temperature variations naturally play a very important rôle, and this is only what might be inferred when we reflect upon the fact that the responses of living beings to heat and cold are fundamental properties of all living matter. The reactions recurring in response to thermic stimuli, before the development of the nervous system, present some interesting features. It has long been known that

[1] *J. Comp. Neurol.*, Vol. 19, 1909.

[2] *Mittheil. a. d. Zoolog. Station*, 2, Neapel, 18 Bd., 2–3 Hft., 1907; *J. Comp. Neurol.*, Vol. 21, No. 4, August, 1911; *J. Experiment. Zool.*, Vol. 11, No. 4, Nov., 1911.

living embryos when placed in various solutions respond with great rapidity to even relatively slight temperature changes occurring in the surrounding media. In the case of the pulsation of the heart many investigators, among whom are Snyder, Carlson, v. Tschermak, and others, determined the temperature coefficient in connection with the activity of this organ. As far as I have been able to determine the extreme sensitiveness of the heart as regards rises in temperature seems to be somewhat greater, or at least the responses are quicker, at a period when the development of the nervous system is well advanced than at earlier stages in the life of the embryo; and I believe the same law holds true with regard to other reactions of the organism. These facts afford an interesting confirmation of the results of observations made by A. G. Mayer with a view to determining the relative importance of the nervous system in the medusa. Mayer has shown that there is greater sensitivity for heat when the muscles remain in contact with the sense-organs than when the connections are severed. The general character of the responses of the embryo in regard to heat, prior to or subsequent to the development of the nervous system, are in a measure comparable to the variations of adjustment of jellyfish for similar stimuli when muscles are either deprived of connection with or allowed to remain in contact with sense organs. In the vertebrate embryo as well as in the medusa the extreme delicacy of response is dependent upon the presence of nerve-elements, and when these have not developed or have been eliminated by experiment the capacity of adaptation of the organism is correspondingly lowered.

The technique used in the experiments is the same in all cases. The chief precaution necessary is to avoid as far as possible subjecting the embryos to changes in temperature and all rough handling; so that the results may not be complicated by the introduction of too many different stimuli.

When the eggs are taken out of the incubator they are opened as quickly as possible, just inside the door of the warm box which covers the microscope, and the embryos are detached from the egg and lifted by means of a horn spoon into the dish containing the solution ($NaCl$ 0.9 — $CaCl_2$ 0.02 — KCl 0.02 — $NaHCo_3$ 0.02 —

glucose 1 per cent., bouillon 10 per cent.). After a little practice the operation of removing the embryo from the egg and placing it in the dish, without either delay or unnecessary shock, may be easily performed. It is obvious that stimuli of a purely mechanical nature up to a certain degree of intensity seem to be less injurious than those caused by variations in temperature.

The effect of rapid changes in position upon the action of the heart during the period represented by embryos of from 12–16 somites is almost a negligible quantity. Embryos that were whisked rapidly about in a dish by means of a camel's hair brush showed no disturbance of cardiac activity; provided of course that the temperature of the solution in which they were placed remained constant.

The primitive responses of these organisms show certain interesting features when elicited in response to various chemical substances used as irritants. In this connection the action of a number of different substances was observed, while that of two was studied in detail. The substances selected for more detailed investigation were strychnia sulphate, an important inorganic nerve stimulant, and thyroid extract, representing organic substances toxic for nervous tissues. After it became possible to eliminate the error attributable to such slight differences in temperature as are apt to occur during manipulation it was found that these two dissimilar substances were strikingly alike in their physiological action upon the heart, if used at a time prior to the development of the nervous system. Even when employed in minute quantities the characteristic accelerating action upon the heart was not observed. As will be noticed in studying the records in the case in which the smallest doses were administered the rate of the cardiac pulsations was not disturbed for some time and only after the elapse of from one to two hours did the action of the heart begin to show symptoms of sagging. In all cases an accelerating action seemed to be entirely absent.

Probably the most intimate correlation which we have yet been able to establish is in connection with the development of the peripheral nervous system. In the case of such substances as cocaine and eucaine we have already shown (*op. cit.*) that there is no inhibitory and reversible action in selachian embryos following ordinary

doses of these drugs until the peripheral nervous system is developed. We find the action of thyroid extract as well as strychnine is modified to some extent by the development of the sympathetic nervous system; an occurrence taking place about the fourth day. We are not yet prepared to state exactly what the character of this mechanism is, although for the present we may consider it highly probable that the increased activity of the heart brought about by moderate doses of the two substances mentioned is the result of the functional activity of the sympathetic system. The symptoms of irregularity in the heart's activities which develop after a certain period deserve consideration and show a remarkable degree of similarity for both strychnia, thyroid extract and magnesium chloride. As will be noticed in chick no. 3 the rapidity of the heart decreased after the embryo was placed in a solution containing thyroid extract. Suddenly, and this seemed to be the characteristic effect of all the substances used—the organ stops pulsating, remaining motionless for a period varying, as a rule, from ten to thirty seconds, or even two minutes. Then it suddenly begins to pulsate again, the rhythm gradually increasing in strength and rapidity until a point of maximum intensity is reached and then after one-half or one minute the cycle ends again. The abrupt manner in which the pulsations cease and the subsequent incidence of the beats, often after prolonged intervals of rest, are strikingly similar to the phenomena taking place when an embryo has been poisoned by an excess of magnesium chloride. In these early stages of development it is extremely interesting to compare the action upon the heart of three substances, possessing chemical qualities as different as thyroid extract, magnesium chloride and strychnine sulphate. The characteristic primary toxic effects as shown in the adult by the rapid rhythm of the heart do not appear until the period when the nervous system has attained a relatively high degree of differentiation.

In addition to the substances already mentioned, solutions of NaOH (1:500) and CH_3OOH (1:500–1:1,000) were employed. No positive results, except a gradual slowing of the heart, were noted in connection with the former, but the latter seemed to exert a marked inhibitory action upon the heart; the stronger solutions

rapidly, and the weaker ones slowly but surely blocking the rhythm. Solutions of adrenaline (1:4,000) and epinine (1:2,000) produced symptoms similar to those following the use of thyroid (1:10,000).

Some of the details of the experiment are given in the following records:

Chick No.	Somites.	Time.	Heart-beats.	Solution.	Results.
1	13	10.7 A.M.	54	Ringer and (1:500)CH_3OOH	
		.11	66		
		.25	—	——	No heart beats.
2	15	12.26 P.M.	96	Ringer and (1:1000)CH_3OOH	Temperature of fluid above normal.
		.28	69		
		.31	78		
		.33	66		
		.40	78		Rises and falls in heart rate due to temperature changes.
		.45	66		
		.47	75		
		.50	70		Contraction of heart was shallow and snappy.
3	13	10.17 A.M.	52	Ringer and Thyroid (1:10,000) at 10.22	
		.23	48		
		.30	48		
		.45	48		
		11.06	51		
		.16	48		
		.57	51		
		12.31 P.M.	54		
		1.00	44		
		.35	36		
		2.11	33		Pulsations very weak but regular.
4	13	3.50 P.M.		Ringer's solution alone	
		.54	26		
		4.00	42		
		4.20	42		
		.57	42		
		5.35	42		
		.47	42		Heart beating very feebly.
		9.30	60		
5	14	4.35		Ringer and Thyroid (1:15,000)	
		.37	72		
		5.00	72		
		.44	60		
		.53	60		
		10.00	48		Individual pulsations strong, but broken by periods of complete rest.

The special instances which we have cited are a few taken from a long list of experiments and the results as given may be considered to be characteristic of all the cases observed. It is quite unnecessary to repeat in detail the experiments in which strychnia sulphate was used as the results for solutions varying in strength from 1:5,000 to 1:10,000 practically corresponded with the records for thyroid extract.

An extremely interesting field of work lies in the direction of determining with more exactitude than has yet been done the varying degrees of responsiveness of the organism to these toxic agents at different periods in the early development of the embryo. An exceedingly complicated problem but one of great importance would be the determination, if possible, of the change in the symptoms as the embryo develops and the probable progressive increase in the permeability of the cells for the different solutions. This question must be solved before we can appreciate the character of the changes in the reactions taking place within the organism when the control of functions is taken over by the nervous system.

PRINCETON UNIVERSITY,
April 18, 1913.

RELIEF MAP OF THE TERRESTRIAL GLOBE.

Illustrating the relations of the mountains to the sea, which has uplifted great walls along the borders of the Continents, by the expulsion of lava from beneath the ocean and its injection under the land. This impressive view of the Earth shows at a glance that the mountains have been formed by the Sea. From Frye's *Complete Geography*, by permission of Ginn & Co., Publishers.

FURTHER CONSIDERATIONS ON THE ORIGIN OF THE HIMALAYA MOUNTAINS AND THE PLATEAU OF TIBET.

(PLATES XXIII–XXXIII AND XXVII *bis* AND XXXI *bis.*)

BY T. J. J. SEE.

(*Read April 18, 1913.*)

1. INTRODUCTORY REMARKS.

The four memoirs dealing with the cause of earthquakes, mountain formation and kindred phenomena connected with the physics of the earth, which the writer had the honor to communicate to this Society in the years 1906–08, and have published in the *Proceedings,* have laid the foundations of a new theory of the physics of the earth's crust. The new theory already is widely adopted by the most eminent investigators, and the purpose of the present paper is merely to add a final confirmation of some interest.

During the past five years the writer's attention has been so fully occupied with the problems of cosmogony that the problems relating to geogony, or the formation of the earth, have been left largely in abeyance; and yet some new light has been shed on them, especially by the researches showing that the lunar craters are due to impact, and thus in no way similar to terrestrial volcanoes, as was so long believed.

Quite recently it was thought worth while to reëxamine the phenomena of the earth's crust, in the light of the new science of cosmogony, resulting from the researches of the past five years. For in studying the problem of the origin of the Himalayas and the plateau of Tibet some important considerations were brought out that were not included in my former papers, and thus it seems advisable to place them on record as confirming and extending my former investigations.

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Moreover, the subject of the origin of the Himalayas is attracting attention abroad. Apparently without knowledge of my work* Colonel Sidney G. Burrard, R.E., F.R.S., surveyor-general of India, has been devoting considerable attention to the subject in "Professional Paper No. 12, Survey of India," a summary of which is given in *The Observatory* for November, 1912, p. 413:

"It may be remembered that several years ago Col. Burrard showed that there appears to be a subterranean mass of great density lying across India in mean latitude 23° North. He now shows that the observations indicate the existence of a line of low density between this subterranean mass and the Himalayas, and suggests that there was, or is, one long crack in the earth's subcrust extending from Sumatra round the Arrakan coast across northern India, through the Persian Gulf to the Mediterranean, traces of which are seen in the parallel shores of the Gulf of Oman and the Persian Gulf. The crack has been filled with alluvial deposit across Northern India and in other places, but the Himalayas remain as the result of the rift in the earth, a great mass of matter having been pushed northward. It has been supposed by others that the Himalayan range was formed by the southward advance of the northern part of the Asiatic continent on to the Indo-African tableland."

The idea here developed by Colonel Burrard, including especially the light material under northern India, and the pushing of the Himalayas northward, is so very similar to that developed in my memoirs that it must be regarded as an independent confirmation of the theory that the mountains are formed by the sea. And as this conclusion applies to the greatest and most intricate range in the world, the external relations of which are not entirely simple, I deem it worthy of attention.

Finally, it may be noted that much interest has been awakened in this subject in England and other countries of Europe. The new theory already is widely taught in the schools of Great Britain and the continent; and in his new work "The Growth of a Planet" (The MacMillan Co., New York, 1911), the London geophysicist Mr. Edwin Sharpe Grew, M.A., concedes that the author's reasoning on the Aleutian Islands is unanswerable, and finally says:

* Since this paper was written Colonel Burrard informs me that to his regret he had not seen the papers of 1906–8, and seems to regard the new theory as quite well established.

"Dr. See has arranged his facts with great ingenuity, and the presentation of his case is the most powerful argument which has ever been advanced in favor of the view held since the days of Strabo, Aristotle or Pliny, that the expansive force of steam is the prime cause of volcanic and seismic disturbances."

In view of this general interest a few additional considerations on the origin of the Himalayas may be important. For after careful reflection I regard the Himalayas as the crucial test; and as the theory is triumphantly verified by a more complete study of this great range, it must hereafter be regarded as firmly and permanently established.

2. The Volumes of the Plateaus of the Rocky Mountains, of the Andes, and of the Himalayas.

In the four memoirs included in the *Proceedings* of this Society for 1906–08, the new theory of mountain formation is treated with considerable detail, but some numerical relations between the plateaus above mentioned are worthy of more attention than they have yet received.

The Pacific plateau of North America is of variable width, being less than 500 miles wide in Mexico, and perhaps 600 miles wide in Canada, but from 1,000 to 1,500 miles wide in the United States. Perhaps 750 miles wide would be a good average estimate of the whole plateau. And the height may be taken as approximately 5,000 feet, or a mile above the sea. These average figures will satisfactorily represent the Pacific plateau in North America. It is noticed also in many places that where the plateau is broadest it is of less average height; but where it is narrower the height is somewhat increased.

In the Andes the same principles prevail. The plateau is highest in the region of Lake Titicaca, where the elevation is over 12,600 feet, or 2.5 miles. The width here does not exceed 300 miles. Further north, near Quito, it narrows up, and is not over half this width; but in Colombia it again spreads out to a width of 300 or 400 miles, but is only about 6,000 or 8,000 feet in height, scarcely more than half that along the more southern portion of the Andes.

It is noticeable that the height decreases from 12,600 feet near Lake Titicaca, to 11,000 feet in central Peru, and perhaps 10,000 feet at Quito; while south of Titicaca the height does not decrease appreciably till central Chile is reached, after which it falls steadily till the continent sinks beneath the sea at Cape Horn.

Now it is remarkable that if we take a typical section of the highest and broadest part of the Andean plateau, 2.5 miles high by 300 miles wide, the numerical product of width by height in miles is 750. And the Rocky Mountain plateau, 1 mile high and 750 miles wide, gives the same product, 750 square miles.

To be sure this product can be varied considerably by taking different sections of the plateaus of North and South America, but all in all this average estimate appears to be a fair one. For in the article "Andes," in the encyclopedia Britannica, 9th edition, Sir Archibald Geikie estimates the bulk of the Andes as of the average width of 100 miles, and height of 13,000 feet. The present estimate gives greater width but somewhat less height.

On the whole, I am inclined to think that the average sectional volume of the Andes is somewhat less than that in the Rocky Mountain plateau; for between Colorado and the Pacific coast the width is about 1,500 miles, and the average height about a mile. The plateau is much narrower in Canada, and very much narrower in Mexico, practically disappearing entirely in Central America and Panama. Thus at one point in the United States the sectional contents may be twice that in the Andes; yet the average sectional volume for the Pacific plateau of North America is not much greater than the larger sectional volumes for the plateau of the Andes.

The significance of this equality in the volumes of the two plateaus lies in the fact that both are the product of the common Pacific Ocean, one in the northern, the other in the southern continent. The new theory does not require that the volumes should be exactly equal, but it implies that they should be comparable, and such is the fact in a very striking degree.

Let us now consider the plateau of Tibet, in comparison with that of the Andes. The height of western Tibet is about 15,000

feet, while eastern Tibet has an elevation of only 11,000 feet. The breadth also varies from some 200 miles on the West to 500 miles at the eastern extremity (General Strachey, article "Himalayas," Encyclopedia Britannica, 9th edition).

Accordingly, if we take the wider part of western Tibet as having a sectional height of 3 miles and a breadth of 250 miles, the product in miles is 750, exactly the same as in the Andes and the Rocky Mountains. Further east in Tibet the width may be 500 miles, and the height about 2 miles, which gives a sectional product of 1,000. This is larger than the average Andean product adopted above, and more like that of the Rocky Mountain plateau west of Colorado.

But the circumstance that the sectional volumes of three great plateaus in the three leading continents of the globe should all be so nearly equal is fully as impressive a fact as the related fact that all of these plateaus should overlook the same great ocean by which they were elevated.

Altogether the similarity in the volumes of sections of these three greatest plateaus is so striking as to make it difficult to deny that it constitutes practically a mathematical demonstration that these plateaus were uplifted by the Pacific Ocean. The relationships here brought out as to the volumes of these plateaus, in addition to the situations about the Pacific Ocean could not well be accounted for by chance, even if we did not know the cause of mountain formation. But as the cause of mountain formation is fully understood, the cause which has built the plateaus is also clearly shown, and it is impossible to consider any other explanation than that here outlined.

3. General Law that where a Continuous Plateau Increases in Width, it Decreases in Elevation.

This law doubtless results from the process of uplifting by which the mountains and plateaus have been raised above the sea. For example, in case of the continuous plateau crowned with mountain crests which surrounds the Pacific Ocean from Cape Horn to Alaska, and then extends down the southeastern shores of Asia,

runs westward through India, and down the east shore of Africa to the Cape of Good Hope, it is observed in each of the four continents traversed that where the plateau is highest it usually narrows in width, and *vice versa*.

Thus we have seen that the plateau of the Andes is high in Chile, Bolivia, Peru and Ecuador, but in Colombia falls to about half its former level, and expands to about double width. This expansion of the width of the plateau in Colombia is characteristic of plateau formation in general. There are slight exceptions to the rule, but the conformity to it is much more noticeable. For example, at Titicaca the width is about 250 miles, but some distance north of this region the Andean Plateau seems to narrow up till the width scarcely exceeds 150 miles, in Ecuador; but it then spreads out again as the range enters Colombia.

It is not easy to explain this narrowing of the range, unless the great width and great height at Titicaca are due to the indentation of the coast at this point, giving uplifting forces from both directions, at the same time. This explanation seems to be well founded, and is confirmed by the corresponding effect north of central India, where the plateau of Tibet reaches its maximum elevation.

Accordingly, we probably should conclude that the width of the Andean plateau is normally less than at Lake Titicaca, and that the width there is due to a combination of forces from the two lines of coast, meeting at an angle of about 135°. It is therefore a fact in South America that wherever the plateau is widest, it decreases in elevation, as in Colombia.

In this problem of uplift, however, something depends on the depth and width of the adjacent elevating ocean, and thus a certain amount of variety should result. Since the adjacent sea is not of uniform effectiveness, we should expect minor deviations from the law; but obviously they should not be too pronounced.

In North America, the same general law holds true. Wherever the plateau is narrow, as in central Mexico, the elevation is great; but where it is wide, the elevation generally is lower. There are of course some exceptions to the rule, but it generally holds true.

For example, along the Rocky Mountain range the highest part

of the plateau probably is in Colorado, where the whole Pacific plateau is widest; but this only indicates that the forces which raised such high mountains as Pike's Peak also raised a high plateau in the general region, independent of the width of the plateau afterwards elevated from the sea. And so on generally.

The rule that the plateau decreases in height when it increases in width, must be understood to apply to a region of not too great width. For when the width is very great, we have rather a series of plateaus added together side by side than a single one; and the final result is a composite effect, one *plateau section* fitting onto another, and the whole series of sections running together as an unbroken embankment of variable height.

In view of these considerations, a plateau so wide as that between Colorado and California is really a series of plateaus, each of unusual width at this point, and the whole effect therefore a very broad compound plateau. The entire Pacific Plateau is the cumulative work of the ocean, done in successive sections; and as the ocean is deepest opposite California, the uplift naturally has been greatest in this part, which also developed the Sierra Nevada Mountains, and at a still earlier stage the Wasatch range in Utah.

The history of the building of the Pacific plateau from Colorado to California is too long to be described here, but these hints on the method by which it was elevated give some idea of the growth of the continent westward from the ancient border which was east of the present Rocky Mountain range.

4. The Cause of the Great Height of the Plateaus of Western Tibet and Titicaca.

Since writing the memoirs of 1906–08, I have had occasion to reëxamine the relationships of the great mountains to the plateaus, and of the plateaus to the sea, with the result of confirming in the most conclusive manner the uplift of the plateaus by the ocean. It is found that the plateau of western Tibet has almost exactly the relationship to the ancient sea valley formerly covering northern India, that the plateau of Titicaca now has to the border of the Pacific Ocean.

If we examine a good map of northern India, we shall find not only that the Indus and Ganges now flow in the ancient sea valley formerly depressed below the waves, and now elevated less than 1,000 feet above the ocean; but also that this valley made a sharp bend in north central India. It has the form of the Greek letter lambda, Λ, with the Ganges leg of the lambda by far the longest, and the included angle about 105°.

If the lava expelled from beneath this ancient sea valley came from two directions, at such an angle, the forces of uplift naturally would accumulate at the head of the Sea Valley. For they would come from the southeast and also from the southwest, as well as from the south; and the result of compounding these forces would be magnified forces of unusual intensity, directed to the elevation of the Himalayas of north central India. This is exactly what has taken place; and hence we see why the plateau of Tibet is so high in the western part of that great "roof of the world."

If now we turn to the region of Lake Titicaca, in South America, we find an exactly similar relative situation. The coast from the south and northwest meet at an angle of some 135°; and the forces producing the uplift have come from the two directions; and also from the west. The result has been a convergence of the forces tending to produce an uplift; but as the angle of 135° is less acute than in northern India, where the angle is 105°, it is not remarkable that the plateau of Titicaca is less elevated than that of western Tibet, where the forces converged more powerfully and were so compounded as to produce the maximum elevation.

It certainly is not accidental that these two highest plateaus of the world stand in *similar centers of converging forces directed from the ocean;* and that the higher plateau of Western Tibet has the forces converging at the smaller angle of 105°, and therefore compounding more effectively to produce a greater power of uplift, for equal energy directed from the side of the sea.

And as the observed phenomena confirm the theory in every detail, one finds it very difficult to believe that any other cause has shaped these stupendous uplifts of the earth's crust.

It is also easy to see why the heights of the plateau of Tibet is

less towards the east, where the elevation is only 11,000 feet. For in the eastern part only a side pressure was available for the uplift, and the forces of elevation did not converge towards a point, as in western Tibet and near Lake Titicaca, in Bolivia.

5. Some Phenomena Connected with the Great Earthquake at Arica, August 13, 1868.

One of the most important means of judging of earthquake phenomena is the evidence afforded by eye witnesses; and this becomes especially valuable when we know the nature of earthquake processes, because it then becomes possible to see in the descriptions given by eye-witnesses a certain amount of new meaning.

Accordingly, we add a brief account of the terrible earthquake at Arica, August 13, 1868, which was a continuation of the movements directly concerned with the uplift of the plateau of Titicaca. For it was a survival of the ancient movements which brought about this elevation, and as the region still is near the sea, it is of special interest, because it bears on the elevation of the plateaus of the Himalayas, now further inland.

In his "Light Science for Leisure Hours," p. 199, the late Professor R. A. Proctor describes the havoc wrought by the earthquake at the neighboring town of Arequipa as follows:

"At five minutes past five (P. M.) an earthquake shock was experienced, which, though severe, seems to have worked very little mischief. Half a minute later, however, a terrible noise was heard beneath the earth; a second shock more violent than the first was felt; and then began a swaying motion, gradually increasing in intensity. In the course of the first minute this motion had become so violent that the inhabitants ran in terror out of their houses into the streets and squares. In the next two minutes the swaying movement has so increased that the more lightly built houses were cast to the ground, and the flying people could scarcely keep their feet. 'And now,' says Von Tschudi, 'there followed during two or three minutes a terrible scene. The swaying motion which had hitherto prevailed changed into fierce vertical upheaval. The subterranean roaring increased in the most terrifying manner: then were heard the heart-piercing shrieks of the wretched people, the bursting of walls, the crashing fall of houses and churches, while over all rolled thick clouds of a yellowish-black dust, which, had they been poured forth many minutes longer, would have suffocated thousands.' Although the shocks had lasted but a few minutes, the whole town was

destroyed. Not one building remained uninjured, and there were few which did not lie in shapeless heaps of ruins."

This description was drawn for the phenomena observed at Arequipa, but that it would serve equally well for Arica is sufficiently indicated by the accompanying photographs of the town as it was before and after the earthquake. A more terrible record of desolation could hardly be imagined.

With this brief but striking description of the earthquake, we may now turn to the seismic sea wave at Arica, and here I shall again quote Proctor's account, which is based on the elaborate technical memoir prepared by Professor F. Von Hochstetter in the *Sitzungsberichte* of the Vienna Academy of Sciences for 1868, Vol. LVIII., Abth. II. Proctor's account runs thus:

"At Arica the sea wave produced even more destructive effects than had been caused by the earthquake. About twenty minutes after the first earth-shock (*i. e.*, 5:25 P. M.) the sea was seen to retire, as if about to leave the shores wholly dry; but presently its waters returned with tremendous force. A mighty wave, whose length seemed immeasurable, was seen advancing like a dark wall upon the unfortunate town, a large part of which was overwhelmed by it. Two ships, the Peruvian corvette *America* and the United States 'double-ender' *Wateree* were carried nearly half a mile to the north of Arica, beyond the railroad which runs to Tacna, and there left stranded high and dry. This enormous wave was considered by the English Vice-Consul at Arica to have been fully fifty feet in height.

At Chala, three such waves swept in after the first shocks of earthquake. They overflowed nearly the whole of the town, the sea passing more than half a mile beyond its usual limits.

At Islay and Iquique similar phenomena were manifested. At the former town the sea flowed in no less than five times, and each time with greater force. Afterwards the motion gradually diminished, but even an hour and a half after the commencement of this strange disturbance, the waves still ran forty feet above the ordinary level. At Iquique, the people beheld the inrushing wave whilst it was still a great way off. A dark blue mass of water, some fifty feet in height, was seen sweeping in upon the town with inconceivable rapidity. An island lying before the harbor was completely submerged by the great wave, which still came rushing on, black with the mud and slime it had swept from the sea bottom. Those who witnessed its progress from the upper balconies of their houses, and presently saw its black mass close beneath their feet, looked on their safety as a miracle. Many buildings were indeed washed away, and in the lowlying parts of the town there was a terrible loss of life. After passing far inland the wave

slowly returned seawards, and strangely enough, the sea, which elsewhere heaved and tossed for hours after the first great wave had swept over it, here came soon to rest.

At Callao a yet more singular instance was afforded of the effect which circumstances may have upon the motion of the sea after a great earthquake has disturbed it. In former earthquakes Callao has suffered terribly from the effects of the great sea-wave. In fact, on two occasions the whole town has been destroyed, and nearly all its inhabitants have been drowned, through the inrush of precisely such waves as flowed into the ports of Arica and Chala. But upon this occasion the center of subterranean disturbance must have been so situated that either the wave was diverted from Callao, or more probably two waves reached Callao from different sources and at different times, so that the two undulations partly counteracted each other. Certain it is that although the water retreated strangely from the coast near Callao, insomuch that a wide tract of the sea-bottom was uncovered, there was no inrushing wave comparable with those described above. The sea afterwards rose and fell in an irregular manner, a circumstance confirming the supposition that the disturbance was caused by two distinct oscillations. Six hours after the occurrence of the earth-shock, the double oscillations seem for awhile to have worked themselves into unison, for at this time three considerable waves rolled in upon the town. But clearly these waves must not be compared with those which in other instances had made their appearance within half an hour of the earth-throes. There is little reason to doubt that if the separate oscillations had reinforced each other earlier, Callao would have been completely destroyed. As it was, a considerable amount of mischief was effected; but the motion of the sea presently became irregular again, and so continued until the morning of August 14, when it began to ebb with some regularity. But during the 14th there were occasional renewals of the irregular motion, and several days elapsed before the regular ebb and flow of the sea were resumed."

In this excellent account of the great sea wave at Arica, August 13, 1868, Proctor makes no allusion to the U. S. S. *Fredonia,* which was lying at anchor with the *Wateree;* and we add therefore that the *Fredonia* is reported to have been capsized as the wave advanced, and nothing was ever again heard of her, all the officers and crew having been lost with the wreck of the vessel.

The *Wateree* was but little injured, and afterwards used as a hotel. The picture of the stranded *Wateree* here reproduced was made by an officer who visited the scene sometime after the disaster. This valuable historic photograph has been preserved by Mrs. E. V. Cutts, of Mare Island, to whom the author is indebted for this impressive illustration of the effects of this great sea wave.

The previous illustrations show the city of Arica before this earthquake, and the mere wreckage which remained after the innundation of the sea.

In an earlier passage than that above cited, Proctor quotes the description of an eye witness, which tells of the movements of the ships:

"The agent of the Pacific Steam Navigation Company, whose house had been destroyed by the earth-shock, saw the great sea-wave while he was flying towards the hills. He writes: 'While passing towards the hills, with the earth shaking, a great cry went up to heaven. The sea had retired. On clearing the town, I looked back and saw that the vessels were being carried irresistibly seawards. In a few minutes the sea stopped, and then arose a mighty wave fifty feet high, and came in with a fearful rush, carrying everything before it in terrible majesty. The whole of the shipping came back, speeding towards inevitable doom. In a few minutes all was completed—every vessel was either on shore or bottom upwards.'"

6. Pratt's Reasoning on the Density of the Matter Under the Ocean, Plains and Mountains, and its Application to India and the Himalayas.

Pratt's reasoning in regard to the density of the matter in and beneath the crust of the earth, and its bearing on the new theory of earthquakes is described in my paper on "The Cause of Earthquakes, Mountain Formation and Kindred Phenomena Connected with the Physics of the Earth," published in the *Proceedings* of this Society for 1906, pp. 344–346. His main conclusion is stated thus:

"This (deflection of the plumb line) shows that the effect of variations of density in the crust must be very great in order to bring about this near compensation. In fact the density of the crust beneath the mountains must be less than that below the plains, and still less than that below the ocean-bed" (Pratt, "Figure of the Earth," 3d edition, Art. 137, pp. 134–135).

Again:

"The conclusion at which we have arrived in Art. 137, that the parts of the crust below the more elevated regions are of less density, and the parts beneath the depressed regions in the ocean are of greater density than the average portions of the surface, seems to bear additional testimony to the fluid theory. For it shows that notwithstanding the varied surface, seen at present in mountains and oceans, the amount of matter in a vertical prism

drawn down at various places to any given spheroidal stratum is the same, although its length varies from place to place as the earth's contour varies" (idem., p. 162).

This subject of the density of the matter hidden from our view beneath the crust of the earth has also been discussed by the late Professor Henri Poincaré, in an address on "French Geodesy," translated by Professor George Bruce Halstead, and published in the *Popular Science Monthly* for February, 1913. The eminent French geometer reasons as follows:

"But these deep-lying rocks we cannot reach exercise from afar their attraction which operates upon the pendulum and deforms the terrestrial spheroid. Geodesy can therefore weigh them from afar, so to speak, and tell us of their distribution. Thus will it make us really see those regions which Jules Verne only showed us in imagination."

"This is not an empty illusion. M. Faye, comparing all the measurements, has reached a result well calculated to surprise us. Under the oceans, in the depths, are rocks of very great density; under the continents, on the contrary, are empty spaces."

"New observations will modify perhaps the details of these conclusions."

"In any case, our venerated dean has shown us where to search and what the geodesist may teach the geologist, desirous of knowing the interior constitution of the earth, and even the thinker wishing to sepculate upon the past and the origin of this planet."

From this extract it will be seen that the most eminent French authorities recognize the conclusions first formulated by Pratt over half a century ago. It only remains to consider the application of Pratt's theorem to the Himalayas and the plateau of Tibet.

If, as Pratt says, "the density of the crust beneath the mountains must be less than that below the plains, and still less than that below the ocean bed," it is very difficult to see how this could have come about except by the greater uplift of the mountains, by the injection of more light material beneath, while a less amount of such material has been injected under the plains, and scarcely any has remained under the ocean bed, because it tends to work out by the path of least resistance. This is the only explanation which satisfies the observed phenomena, and conforms to the known fact that the mountains and plateaus are uplifted by the expulsion of matter from beneath the sea, in world-shaking earthquakes. Thus the

known facts of geodesy as respects the Himalayas are fully explained. And the explanation rests on principles established by a variety of mutually confirmatory observations.

7. Defects in the Doctrine of Isostacy as Commonly Stated.

The doctrine of isostacy as commonly stated is vitiated by a serious if not fatal error; and it is necessary to overcome this defect if the doctrine is to hold its place in modern thought. In *Science* of February 10, 1911, Professor J. F. Hayford presents a paper based on the valuable data he obtained in the work of the U. S. Coast and Geodetic Survey, deduced from 765 series of astronomical observations at 89 stations in the United States. The causes assigned, however, are so inadequate that it seems worth while to point out the defects in his reasoning, which is as follows:

"Columns *A* and *B* have been assumed to contain equal masses. There is complete isostatic compensation. The pressures at the bases of the two columns are equal, and at any less depth, *X*, the pressure is greater in *A* than in *B*. Now assume that in the normal course of events a large amount of material is being eroded from the high surface of column *A* and deposited on the low surface of column *B*. After this erosion has been in progress

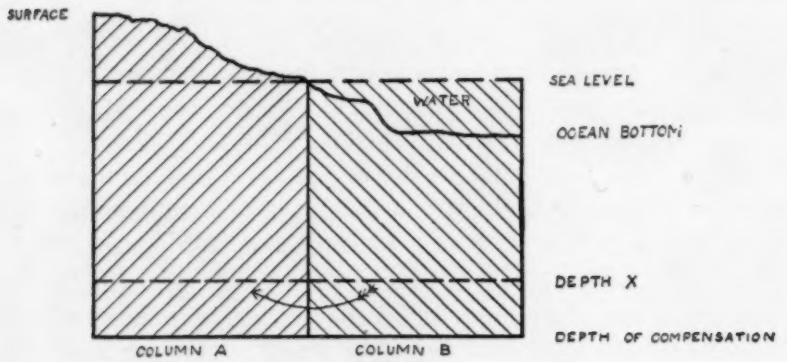


Fig. 1

for some time the isostatic compensation will no longer be perfect. The pressure at the base of *B* will be greater than at the base of *A*. The pressure very near the top of *B* will still be less than at the same level in *A* so long as the top of *A* remains higher than the top of *B*. There will be some intermediate level at which the pressure in the two columns is the same.

Call this level of temporary equality of pressure in the two columns the neutral level. As the process of erosion and deposition progresses the neutral level will gradually progress upward from its original position at the base of the columns. Eventually if no interchange of mass took place between the columns except at the surface, and no vertical displacement occurred in either column, the neutral level would reach the surface when the process of erosion and deposition became complete and the upper surfaces of the two columns were at the same level. During the process of erosion and deposition the excess of pressure in *A* at any level above the neutral level will continually decrease. Similarly, at any level below the neutral level the excess of pressure in *B* will continually increase as the erosion progresses and the neutral level will rise. Thus there will be established a continually increasing tendency for the material below the neutral level in *B* to be squeezed over into *A*. If the stresses tending to produce this undertow from the lower part of *B* to *A* become greater than the material can stand, the flow will take place as indicated by the arrow in the figure. If the material flows without change of volume, as if it were incompressible, the upper part of *A* and its surface will be raised, the upper part of *B* and its surface will be lowered, the neutral level will sink and an approximation to the original conditions with complete isostatic compensation will be re-established."

"This is the general case of isostatic readjustment by the action of gravitation alone. Gravitation tends to produce a deep undertow from the regions where deposition is taking place to the regions where erosion is in progress, in the direction opposite to that of the surface transfer of material."

"Let us suppose that the isostatic compensation at a given stage in the earth's history is practically complete for a continent, that the process of erosion from the greater part of the continent and deposition around its margins is in progress, and that the process of readjustment by a deep undertow is in progress."

The fatal defect in this reasoning consists in the fact that it begs the question, and does not in any way explain the elevation of the margin of a continent, but only how it may maintain its present form by a process of readjustment. This is like a river rising higher than its source, or a man trying to lift himself by pulling on his bootstraps, or the logician reasoning in a circle. For in order to explain the development of the inequalities of the earth's crust, we must not only explain the adjustment and balancing between adjacent parts, but also *how the original uplift came about,* to give the observed contrast in surface levels.

Now on the premises used by Hayford, it is possible to explain how a given inequality of surface levels, when once existing, *can*

be maintained; but it is not possible to account for the *origin of the inequalities of level. Isostacy as thus depicted is not an active creative agency, but simply a negative process for maintaining existing inequalities.* Under the doctrine as above stated, the height of a mountain or plateau could never increase, for that would require the exertion of positive elevating forces, not mere balancing for maintaining inequalities of levels already existing.

Accordingly, this formulation of the doctrine of isostacy is defective, and inadequate to account for the phenomena of the earth's crust.

The true doctrine should include not only the *balancing process* described by Hayford, but also those *elevating forces directed from the sea,* by which the mountains are elevated as narrow walls about the borders of continents, on the great plateaus which spread out as wider embankments beneath them. Without these positive uplifting forces, no continent could ever have a mountainous border thrown up about it.

No doubt the elevation is produced under approximately isostatic conditions. Mountains can be forced up only to a certain height, the transfer of lighter material under the higher parts thus giving nearly equal mass in all equal prisms drawn to the center of the earth. The path of least resistance is towards regions of elevation, and the underlying material expands as the surface level is forced up. If this were not so the greater weight under the elevated region would cause it to subside to the common level. In this way, and in this way only, can progressive elevation be produced.

The weakness of the old method of reasoning is further illustrated by Hayford's remarks:

"Under a region of deposition two effects of opposite sign tend to occur. The effect of increased pressure tends to produce chemical changes accompanied by decrease of volume and so to produce a sinking of the surface. The blanket of deposited material tends to raise the temperature in each part of the material covered, to increase the volume of this material, and thereby to raise the surface. The temperature effect may serve in time to arrest the subsidence caused by increased pressure or even to raise the surface and change the region of deposition into one of erosion."

"The changes of temperature just described are due directly to erosion

and deposition. If as an effect of erosion and deposition an undertow is started tending to reëstablish the isostatic condition, this undertow, a flow of material presumably solid, necessarily develops considerable heat by internal friction. The increase of temperature so produced tends to cause an increase of volume. It may favor new chemical changes, including changes from the solid to the liquid state, which may be accompanied by a change of volume. The undertow tends to be strongest not under the region of rapid deposition, but under the comparatively neutral region between the two in which neither erosion nor deposition is much in excess of the other, see Fig. 2. Hence the undertow by increasing the temperature and causing a change of density may be directly effective in changing the elevation of the neutral region between two regions of deposition and erosion."

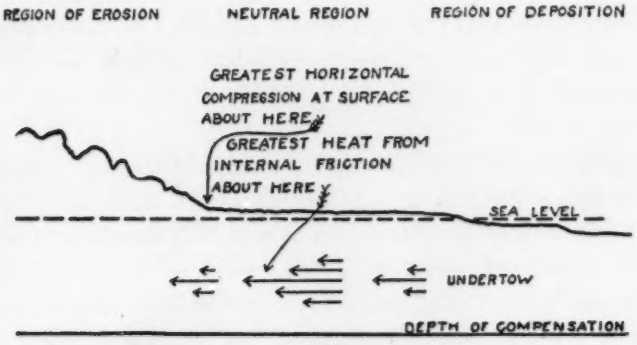


FIG. 2

"Horizontal compressive stresses in the material near the surface above the undertow are necessarily caused by the undertow. For the undertow necessarily tends to carry the surface along with it and so pushes this surface material against that in the region of erosion, see Fig. 2. These stresses tend to produce a crumpling, crushing and bending of the surface strata accompanied by increase of elevation of the surface. The increase of elevation of the surface so produced will tend to be greatest in the neutral region or near the edge of the region of erosion, not under the region of rapid erosion nor under the region of rapid deposition."

The criticism against this reasoning is the same as that used above—namely, it will explain only balancing, but not the uplifting of great mountain walls along the sea coast. Nothing but the transfer of lava from beneath the sea, and the expansion of it under the mountains will explain the observed mountain walls along the borders of continents; and this requires positive forces of elevation, not mere negative processes. The advocates of isostasy, as

heretofore taught, have left that doctrine with such a serious defect that this correction is necessary to give it a rational basis.

8. The Uplifting of the Himalayas, Arrakan and Afghanistan Ranges Explains the Great Asiatic Earthquake belt. Confirmation of Colonel Burrard's impressions that the Himalayas have been Pushed Northward, but not by a Change in the Rotation Period of the Earth.

We have seen that the region now occupied by the rivers Indus and Ganges was formerly a sea valley; and that after the Himalayas were elevated to a great height, the valley itself was slowly raised above the ocean.

If proof is asked that the valleys of the Indus and Ganges were formerly below the sea, it is furnished by the well-established fact that such valleys as the San Joaquin and Sacramento in California were below the sea when the Sierras were being elevated. What has happened in California has also happened in India; and the same process of elevation will eventually give a fertile habitable valley in the belt just south of the Aleutian Islands now covered by a sea nearly five miles deep.

This proof that the valleys of the Indus and Ganges were once several miles beneath the sea level is absolute. For it is definitely known how the mountain ranges and adjacent valleys are crumpled, and finally raised above the sea. And what has happened for mountain ranges in general, has happened also for the Himalayas and the valleys adjacent thereto.

In order to round out the view here traced, it only remains to add that the Arrakan coast of Father India contains two chief mountain chains, one of which is the backbone of the Malay Peninsula; and the other is the range terminating at Cape Negrais, but continuing under the sea in a string of islands, and reappearing further south as Sumatra and Java. The Andaman islands and several volcanoes in the sea appear between Cape Negrais and Sumatra. And both Java and Sumatra are noted for their terrific

volcanic violence. This volcanic chain is analogous to that of the Aleutian Islands, except that the middle part is submerged, and the two ends raised above the waves.

The line of thought here developed enables us to understand the volcanic activities of Farther India, and also the terrible belt of earthquakes in Assam and the adjacent regions south of the Himalayas. Part of the ancient sea valley is above the water as low land, and part still in the ocean, and covered by the sea to a considerable depth.

West of India, we have the complicated mountain ranges and earthquake belts of Afghanistan and Persia. It would be difficult if not impossible to understand the phenomena they present if studied alone; but if studied in connection with the developments of India and Farther India above discussed, it is easy to see that Afghanistan and Persia were built up in like manner, and at no very distant epoch were beneath the sea.

In his article on the "Himalayas," Encyclopedia Britannica, 9th edition, the late General Strachey has strongly emphasized the view that the mountains and table lands of Afghanistan and Persia are intelligible only in connection with those of India.

> "It is after the middle Tertiary epoch that the principal elevation of these mountains took place, and about the same time also took place the movements which raised the tablelands of Afghanistan and Persia, and gave southern Asia its existing outlines."

He also points out the fact that at no very distant geological epoch the ocean extended from the Arabian Sea through the Persian Gulf to the Caspian and Mediterranean. The continuation of the earthquake belt through this region of Western Asia is therefore quite intelligible, and the existence of active volcanoes near the Caspian a survival of present and former relations to the ocean.

The annual rainfall south of the Himalayas amounts to about 36 feet, and this is so enormous as to be almost as effective as a shallow sea in keeping alive earthquake processes.

It is established by observation, for example, that the very

active volcano Sangai, in the terrible rain belt at the head of the Amazon, in Ecuador, has its activity about doubled during the worst period of the rainy season, owing to the effects of surface water. If in South America the volcanic forces can be visibly augmented by copious surface water, it is easy to understand that the terrible rains of India may also operate to keep alive the earthquake processes almost as well as an overlying sea.

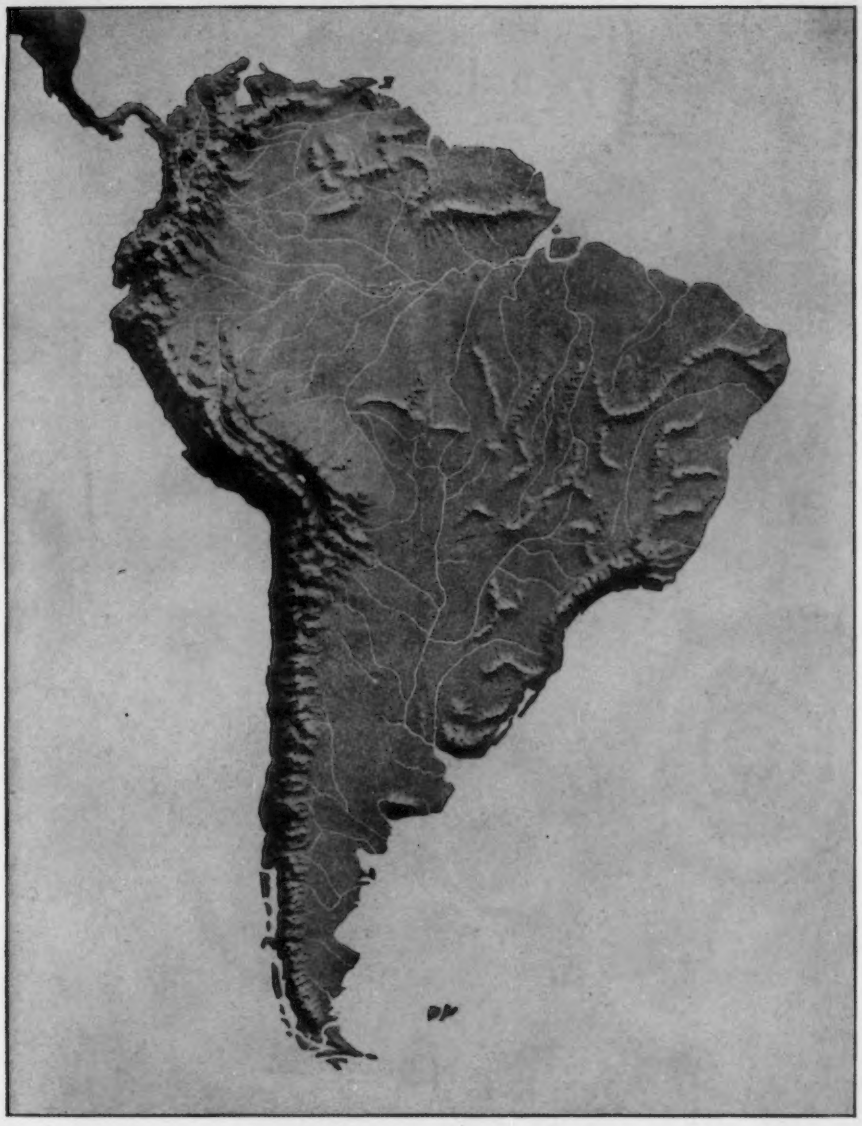
The earthquake belt south of the Himalayas is thus perfectly explained. And the extension of this line of disturbance through to the Caspian presents no difficulty, when account is taken of the recent situation of the sea over a large part of this region of western Asia.

In conclusion it only remains to add that Colonel Burrard's argument, cited in Section 1 above, *that the Himalayas resulted from the pushing of a great mass of matter northward, undoubtedly is correct.* This fact appears to be as well established as the rising and setting of the sun, and further discussion of the subject is superfluous.

The cause of this northward movement is also fully established, but it is not that imagined by Colonel Burrard. In the *Observatory* for May and June, 1912, will be found a discussion by Colonel Burrard of considerable interest, but founded on the premises that the earth's speed of rotation is variable and has undergone considerable changes within the period covered by geological history.

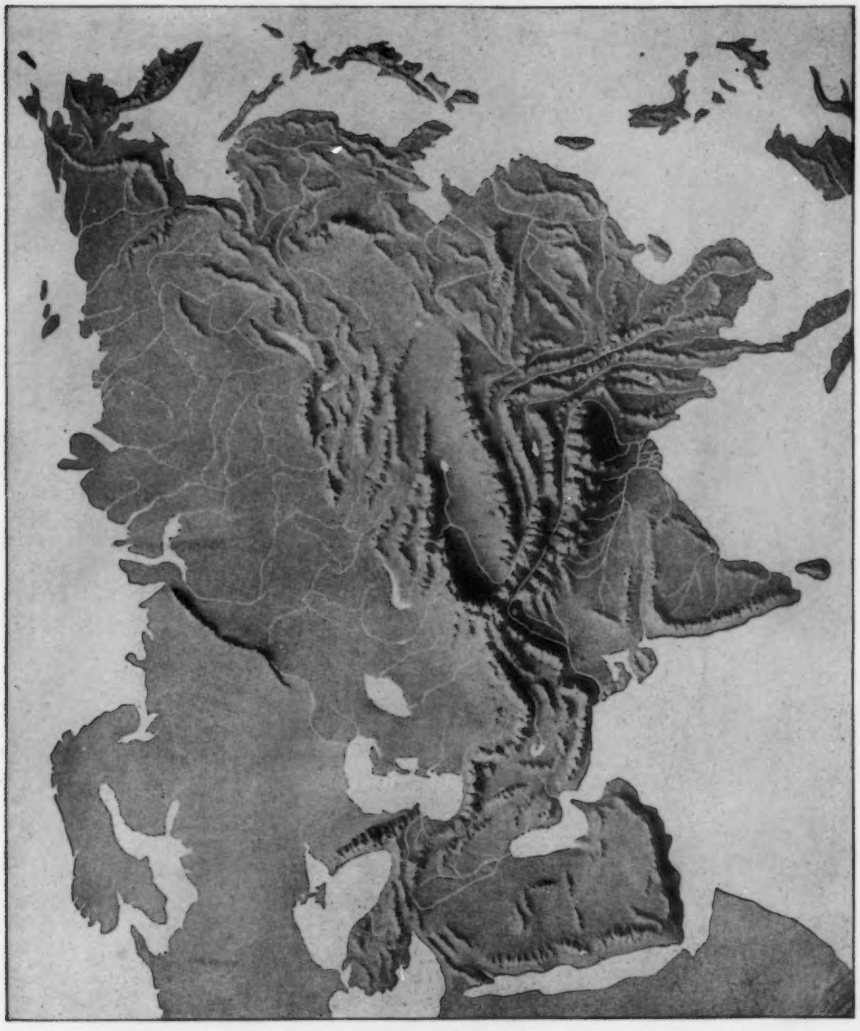
The writer's "Researches on the Evolution of the Stellar Systems," Vol. II., 1910, show that the views formerly held by Lord Kelvin and Sir George Darwin are now quite inadmissible; and that the earth's rotation has not changed sensibly since the earliest geological time. Thus Colonel Burrard's premise that the retardation of the earth's rotation might cause a flow of matter towards the poles is wholly inadmissible.

Besides, there are other means of showing that such was not the origin of the Himalayas. *These great mountains of India, for example, should no more be due to a change in the earth's rotation, than should the Andes, which run almost exactly north and south, and by their course along the meridian, exclude an explanation founded on a change in the speed of the earth's rotation.*



RELIEF MAP OF SOUTH AMERICA.

From Frye's *Complete Geography,* by permission of Ginn & Co., Publishers. Illustrating the New Theory that the Mountains were formed by the oceans, and thus run parallel to the Sea Coast, as in the typical case of the Andes. It was this vast wall along the Western sea-board of South America and the earthquakes afflicting that region that led to the discovery of the cause of Earthquakes and Mountain Formation in 1906. The foundations of the New Science of Geogony were thus laid by the writer, soon after the great earthquakes which devastated San Francisco and Valparaiso.

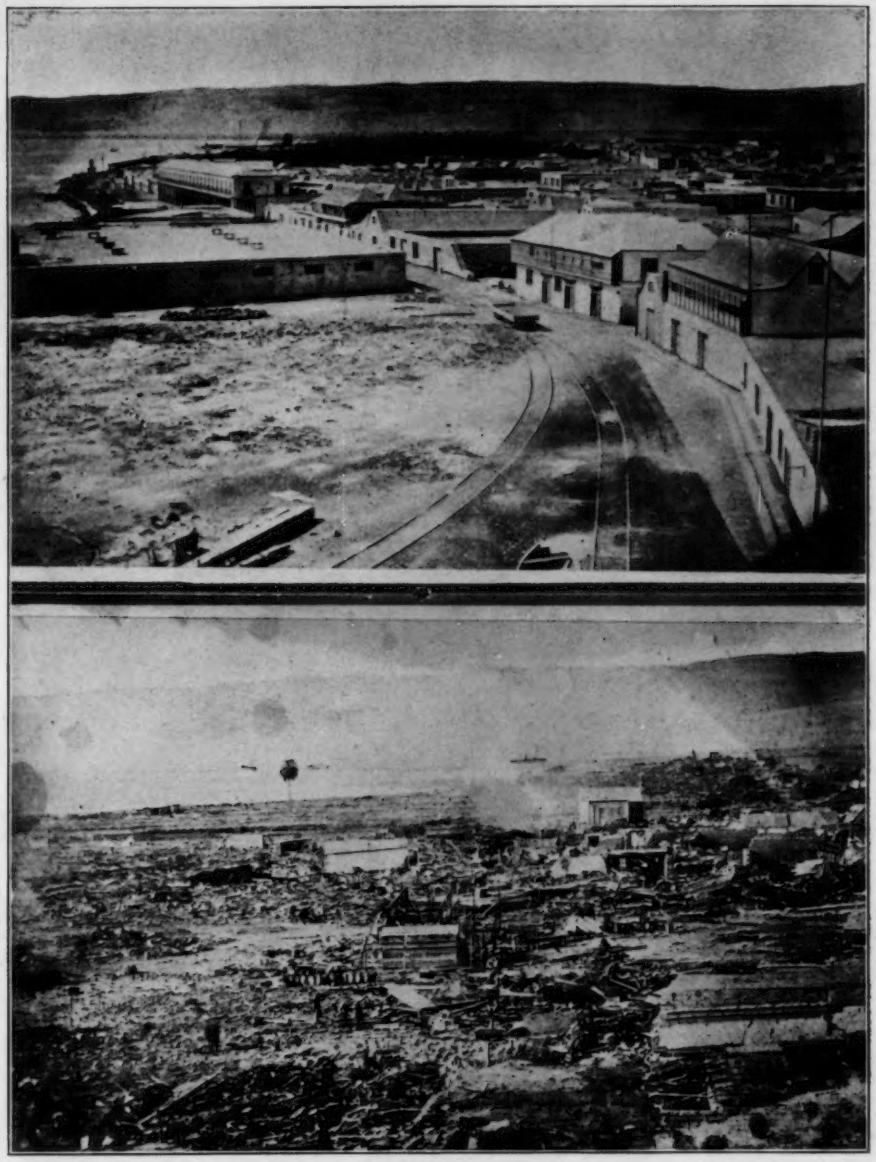


RELIEF MAP OF ASIA.

From Frye's *Complete Geography,* by permission of Ginn & Co., Publishers. Showing the development of the Himalayas and Plateau of Tibet by the Indian Ocean on the South, and other ranges of Mountains by the Pacific, along the Eastern shores of the Continent. Before India was raised from the ocean, the sea coast ran parallel to the Himalayas, as in the case of the Andes in South America.

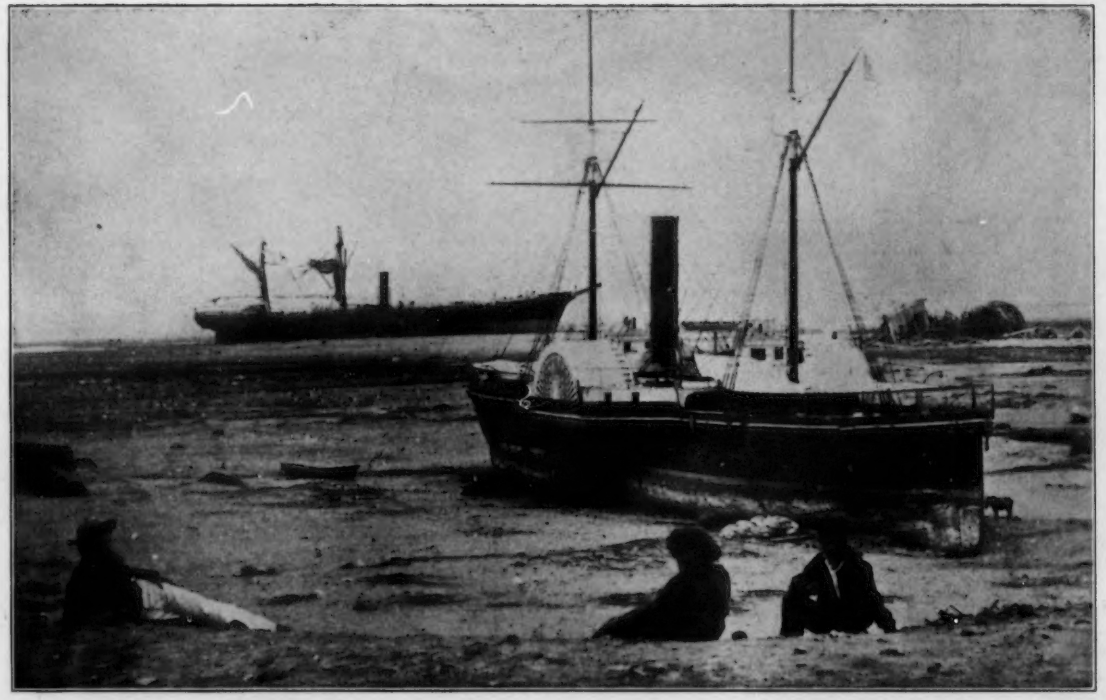
MAP OF INDIA.

From the *Encyclopedia Britannica,* ninth edition, showing the location of the Himalayas and Plateau of Tibet in relation to the neighboring parts of India.



THE CITY OF ARICA, PERU, AS IT APPEARED BEFORE AND AFTER THE EARTHQUAKE AND SEA WAVE OF AUGUST 13, 1868.

From photographs in the possession of Mrs. E. V. Cutts, of Mare Island, California.

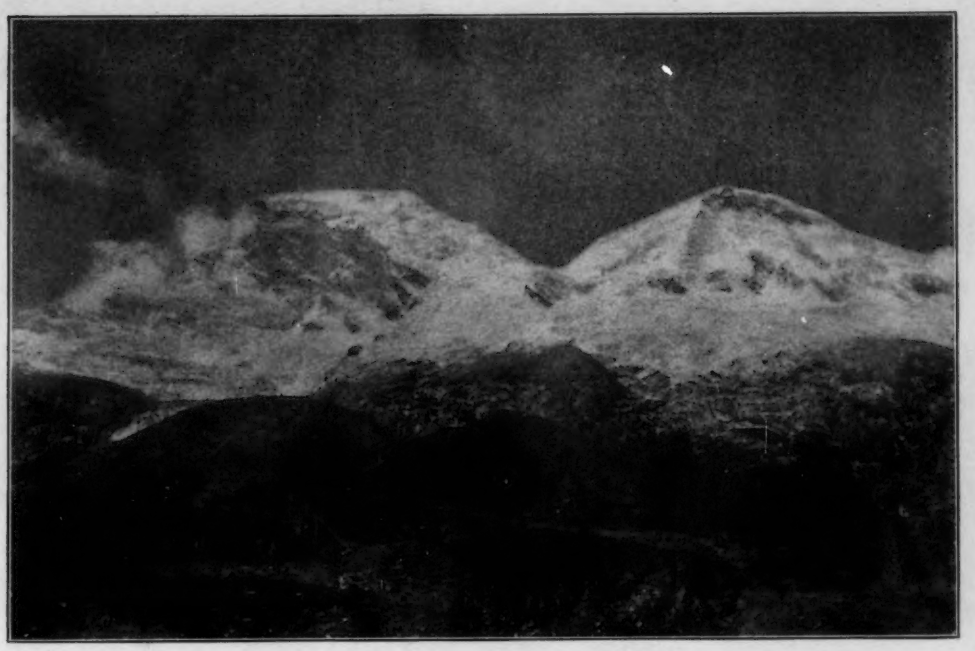


THE SHIP IN THE FOREGROUND IS THE U. S. S. WATEREE.

It was washed half a mile inland by the great sea wave at Arica, Peru, August 13, 1868.
From a photograph in the possession of Mrs. E. V. Cutts, Mare Island.

PASSAGE IN THE ANDES, BETWEEN CHILE AND ARGENTINA.

Showing a Stone House built for the shelter of travelers, against violent storms which are frequent at these great altitudes.
Photograph by Harriet Chalmers Adams, *National Geographical Magazine* for May, 1910.

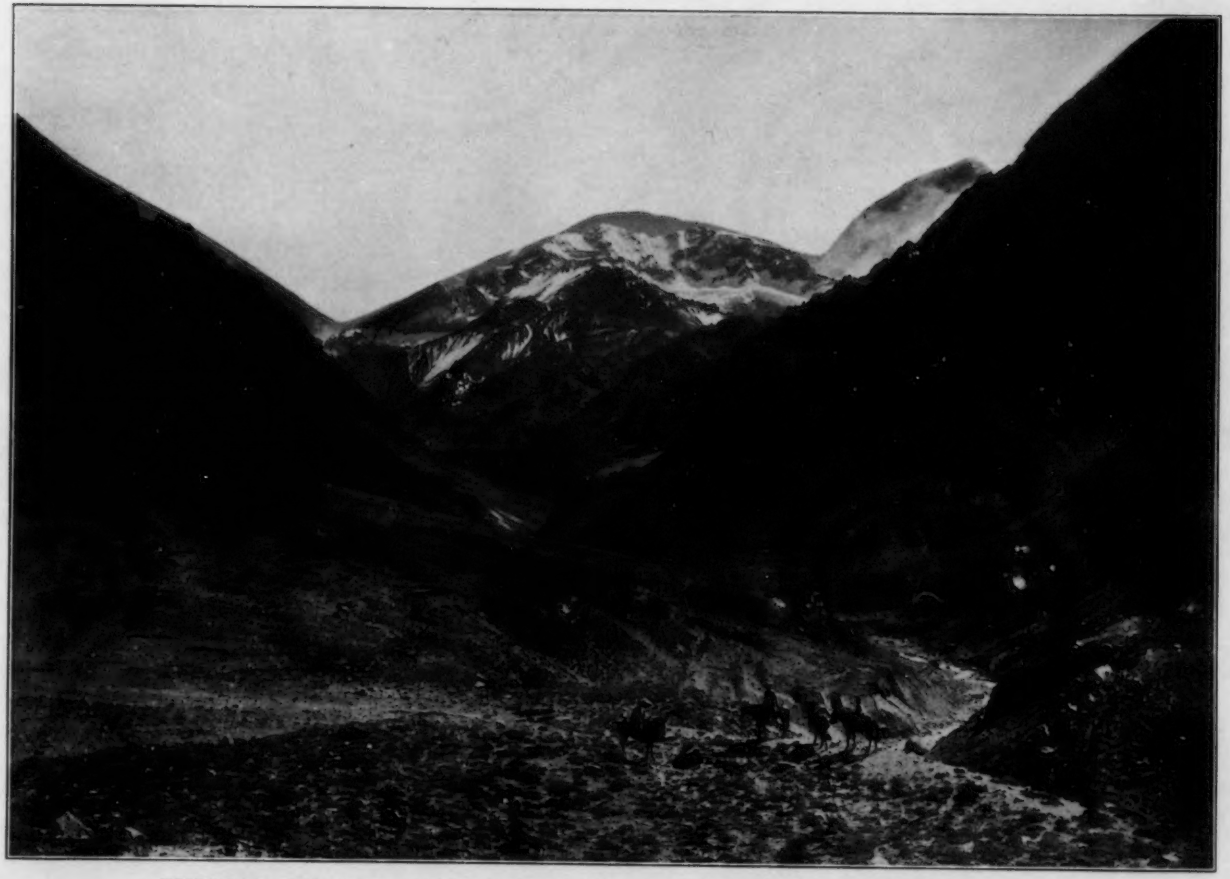


MT. HUASCARAN, IN CENTRAL PERU, ALTITUDE ABOUT 24,000 FEET.

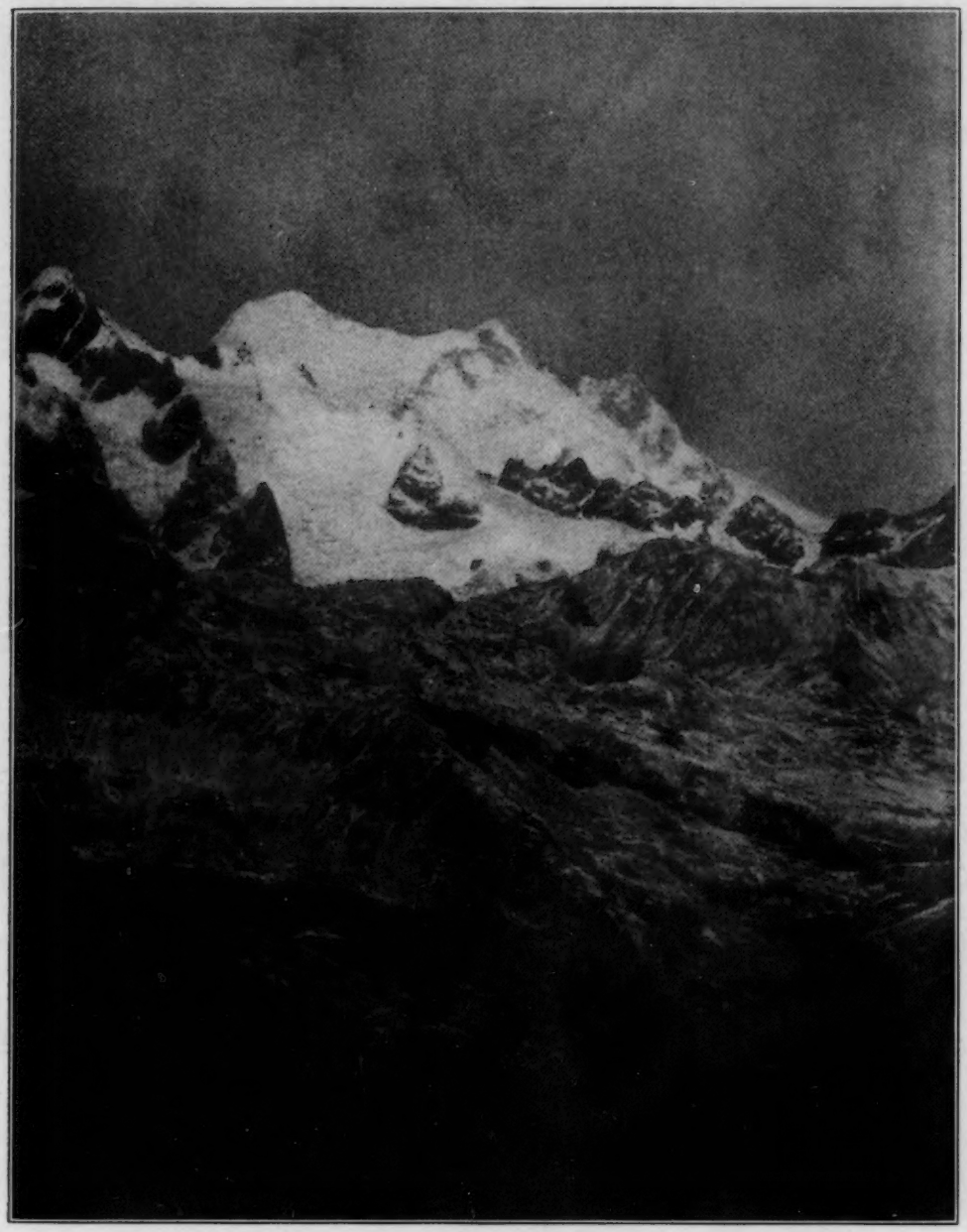
Photograph and copyright by Miss Anna S. Peck, *National Geographical Magazine*, for June, 1909. Used by special permission of Miss Peck.

MT. ACONCAGUA, IN CENTRAL CHILE.

The highest Volcano in the world, and long considered the summit of the Andes. Altitude, 22,800 feet.

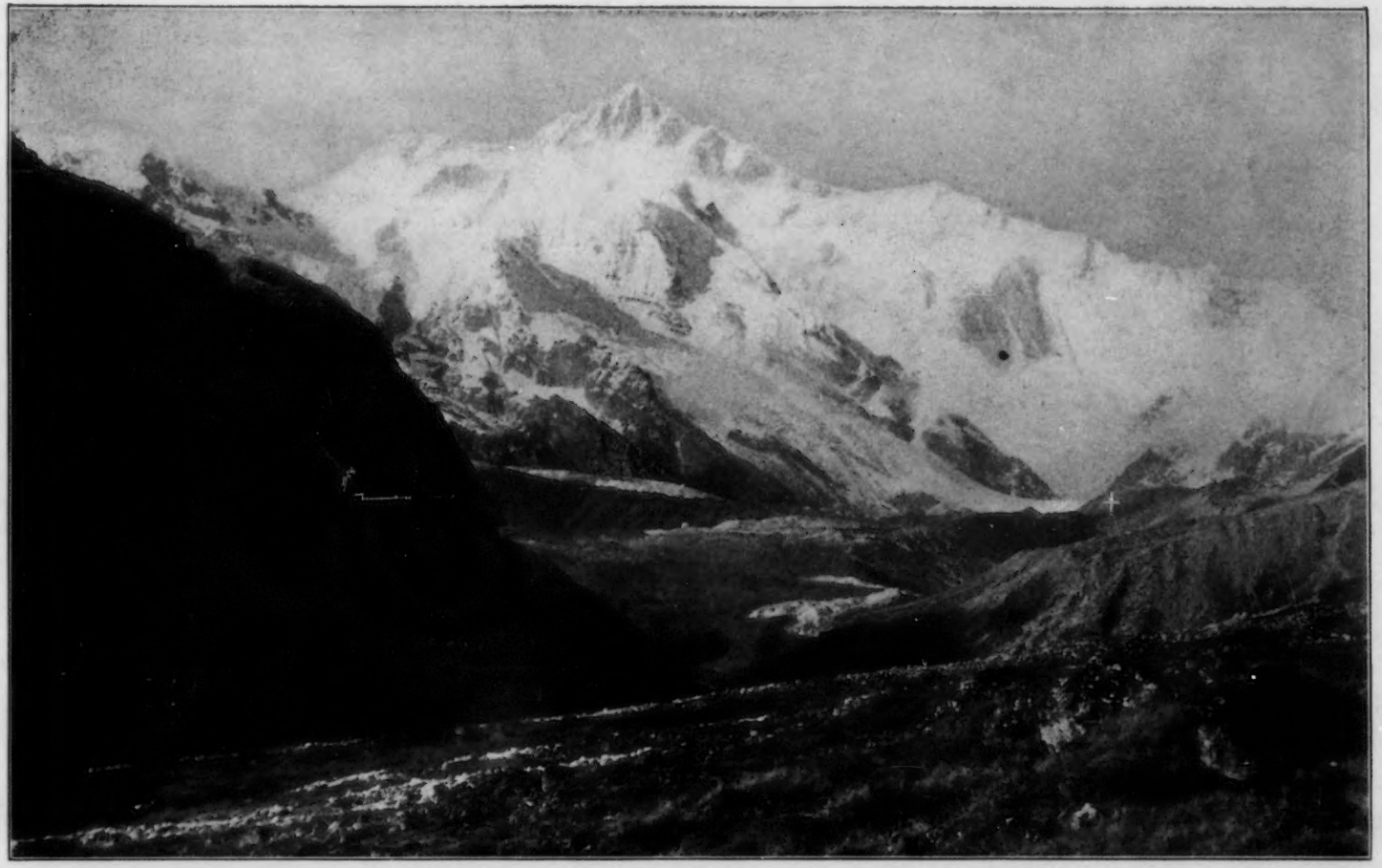


TYPICAL VIEW OF THE ANDES, NEAR ACONCAGUA, CENTRAL CHILE.

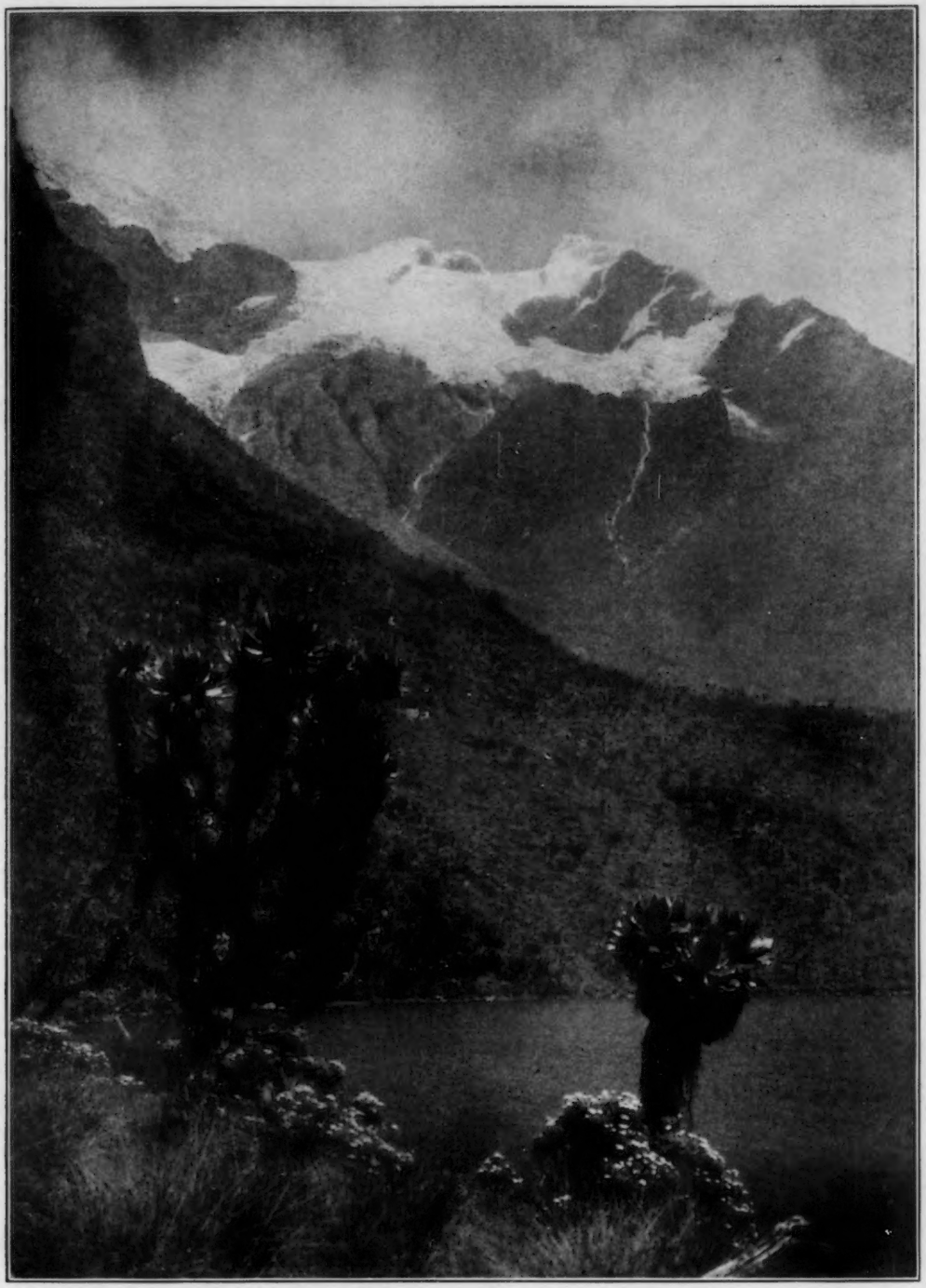


MT. EVEREST, THE HIGHEST PEAK OF THE HIMALAYAS AND OF THE WORLD.

Altitude 29,002 feet above sea level. Photograph by Vittorio Sella, from Chunjerma Pass (Nepal), 80 miles distant, *National Geographical Magazine* for June, 1909.



MT. KENGCHENJUNGA, NEAR MT. EVEREST, AND SECOND HIGHEST PEAK OF THE HIMALAYAS.
Altitude, 28,150 feet. Photograph by Vittorio Sella, *National Geographical Magazine* for June, 1909.



THE RUWENZORI

In Equatorial East Africa rising to an altitude of 18,600 feet. This snow capped range in the hottest part of Africa was explored by the Duke of the Abbruzzi in 1906. Photograph by Vittorio Sella, from the south, *National Geographical Magazine*, for June, 1909.

VIEW OF THE ALPS FROM THE SUMMIT OF MATTERHORN.

Showing the terrible upheavals involved in the uplift of the Alps. Photograph by G. P. Abraham, *National Geographical Magazine* for June, 1909.

And as the Andes are well known to have been formed by the sea, in the way we have described, it is certain that the same cause uplifted the Himalayas and the plateau of Tibet.

From these considerations it will be seen that the modern sciences of geogony and cosmogony are closely related, and that neither can be perfectly developed without the aid of the other. Just as it is impossible to develop a satisfactory theory of the formation of the earth without data drawn from the modern science of cosmogony; so also cosmogony itself has been much improved by a science of geogony which gives a correct theory of terrestrial mountain formation. For that has aided in establishing the origin of the lunar craters, and the early growth of the earth itself by impact. The existing ranges of mountains have been subsequently formed by the sea and thus made parallel to the coasts. On the other hand, without the theory that the mountains generally are formed by the ocean, which is so clearly established for the typical range of the Andes, running exactly north and south, our ideas of the origin of the Himalayas might have remained obscure for ages.

It is scarcely necessary to point out that these results illustrate somewhat impressively the value of a comprehensive vision in the study of the sciences. Without this power for comparing together the most remote objects there can be no progress in discovery of the highest order.

Starlight on Loutre,
Montgomery City,
Missouri,
March 27, 1913.

FACTORS IN THE EXCHANGE VALUE OF METEORITES.[1]

By WARREN M. FOOTE.

(*Received April 25, 1913*)

Historical.—For many years an acceptable standard of meteorite values has been sought by students and investigators in this branch of geology, as well as by those museums or individuals who aim to complete the great collections. While the supply of one locality or fall is often known to the fraction of a gram, its institutional owner's reluctance to exchange may not be measured by any known formula. It is then most natural that negotiations frequently pro-

[1] Since values are not settled by individual, but by collective opinion, an outline of this article was submitted to several active exchangers. The curator of one of the two greatest meteorite collections warmly commends the effort to determine exchange values from new viewpoints. He expresses the belief that museums in general will utilize the work, and will welcome the elaboration of any detailed system which affords a standard of value for meteorite exchanges.

Professor E. A. Wülfing writes:

"Your article on the factors which determine the exchange value of meteorites interested me very much. . . . In my consideration of the matter in 1897, I did not think primarily of market prices, but of exchanges between the large museum stocks, which I thought was not wholly impossible. The purchase price was only considered by me in so far as it influenced the choice between the formulæ W_1, W_2 and W_3. Your second factor, 'weight of specimen offered,' could not influence me, since there seemed to be much too little of what was offered in 1897, in comparison with the large museum-masses to be dislodged. . . . But these were all factors which it was impossible to consider in 1897; likewise the 'area of slice' had to be set aside, otherwise the problem of clearing away the endless confusion in the price question would have grown still more insoluble.

"I would say therefore, that in quite properly criticizing the formula, . . . the conditions which produced it, and which only could have produced it, should be considered. . . . I believe that you have undertaken this [extension of the formula] in the right way and I wish to express the hope that you may succeed in further distributing meteorite masses and thereby advance their study."

long into failure during the years which are required for exchangers to get together. Apart from the few who devote much time to meteorites, are the many to whom they have but an incidental and minor interest, and who have little idea of values other than those given by the owner. Hence the occasional as well as the regular collector may find worth while a brief examination of the subject. We may first exclude local values, since they are usually determined by agreement between finder and buyer.

The first to attempt any systematic enlightenment in this field was Dr. Otto Buchner. In 1863 appeared his volume on meteorites in collections,[2] wherein he noted 230 different localities.

Thirty-four years after Buchner's publication, Professor E. A. Wülfing, an eminent authority, wrote: "The present interest in meteorites on the part of many, could be increased by a wider distribution of material. Believing that this is attainable through active exchanging, and further because I see an aid to this end in a determination of the relative value of meteorites, even if only approximately, I shall endeavor to establish their exchange values." Accordingly, in 1893 he wrote to all owners or curators of meteorite collections, asking them to report the weight of each meteoritic fall or locality in their possession. Then followed a long and voluminous correspondence which, with the arduous tabulation of the data secured and the development of his formula, delayed for nearly four years the publication of his exhaustive treatise[3] of some 500 pages. The major part of this work consists of a list of all known meteorites, giving, for each, the full locality, symbol, date of fall or find, bibliography, original weight, present known weight, and finally, a list of owners with the weight in grams of their holdings. In the two concluding chapters is elaborated a theory of values. He finds but three important factors which enter into the value of each meteorite:

1. The Present Known Weight.—This, Wülfing states, is incomplete in many cases, because of his failure to reach some owners and to secure full data from others. Where the original weight is un-

[2] "Die Meteoriten in Sammlungen, ihre Gewichte, mineralogische und chemische Beschaffenheit."

[3] "Die Meteoriten in Sammlungen und ihre Literatur," Tübingen, 1897.

accountably reduced, some of the shortage is considered in the exchange value given to such falls.

2. The Group Weight.—A modification of the admittedly imperfect Rose-Tschermak-Brezina group classification, is used, showing each group weight.

3. The Number of Owners.—Wülfing acknowledges the unreliability of this factor, in that some owners have not enough to part with any and should therefore not be included. However he includes all owners as of equal importance in his formula for finding the value of a fall, arguing that when divided among many holders, it is less desirable in other eyes.

The following variable factors, which he excludes, are then referred to as not being computable or as of insufficient weight to be utilized in working out the formula: (4) Material which may be found in the future and thus raise certain group-weights, especially of the rarer groups, when new individuals of such are found, (5) the original cost of collecting specimens, (6) state of preservation, (7) historical interest, (8) if seen to fall, the meteorite is valued higher, especially in the case of nine irons so distinguished. The wisdom of doubling his valuation of these nine falls, or making even a greater increase, is left by Wülfing as an open question. Concerning the stones, he states that there is generally no difference in value between the few not seen to fall and those seen to fall.

The author here begins a mathematical inquiry into the relative value of the three factors chosen; Group Weight (G), Present Known Weight (N), and the Number of Owners (B). Following a long analysis with numerous allowances and exceptions, he establishes the exchange value (W) in the formula,

$$W = \frac{1}{\sqrt[3]{GNB}}$$

Four tables follow for estimating the value of new meteorites: the first is for meteorites having from 1 to 3 owners; the second 4 to 8 owners; the third 9 to 20; the fourth table being for those of 21 or more owners. The group weight is given vertically and the locality weight horizontally. At the intersection of these lines is a numeral indicating the exchange value per gram, taking the value of Canyon

Diablo as unity. It is thus not a money value, but an exchange value index.

In the next chapter is a group classification of all meteorites known in 1897, giving figures under U (original weight), N, B and W for each fall. In the determination of U and N and in their discrepancies, many uncertainties arise, and on this account two values are given for some falls and other values are omitted altogether. In some of his value-pairs Wülfing indicates the less probable of the two within parentheses. Again where both values are doubtful, they are enclosed in brackets.

In 1899, the late Professor E. Cohen, author of many important scientific studies of meteorites, published a table[4] collating the Wülfing exchange values with the trade prices of eight dealers. For each fall, he showed in one column the lowest dealer's price in pfennigs, then the highest, and in a third column the medium or average of all prices. The Wülfing exchange values ($\times 13$) he gave in a fourth column. This table afforded a basis for comparing the theoretical exchange value with the actual market price of each fall.

Professor Cohen called attention to the fact that previously no account had been taken of the area of a slice, maintaining that this feature should receive full consideration in estimating the value. Examining the tabulation, he pointed out that about one third of the falls compared, showed large variations between the medium trade price and the Wülfing exchange value. Most of the relatively low figures of Wülfing he ascribed to the fact that although the masses are very large, they are securely held against partition by sale or exhange. On the other hand, many of Wülfing's relatively high figures are due to the fact that they belong to the rarer groups, which, according to Wülfing's critic, come on the market only by chance, and with no fixed value. Finally Cohen stated that it is not the number of owners which affects the value of a particular fall, but the number of owners who are able to part with some of their holding, a collector of pieces under 15 to 30 grams being

[4] "Über den Wülfing'schen Tauschwerth der Meteoriten im Vergleich mit den Handelspreisen," *Mitth. aus dem naturwiss. Ver. für Neu-Vorpommern u. Rügen*, 1899, XXXI., pp. 50–62, Greifswald.

negligible in an estimate of available exchange material. He concluded his review with a conditional acceptance of the exchange basis established by Wülfing, and welcomed his guidance among those final personal factors which in the past have rendered meteorite exchanging so difficult a process.

In 1904 the late Professor Henry A. Ward, the greatest traveling collector of meteorites, made a new collation[5] of seven dealers' prices, contrasting his results with those of Cohen. Professor Ward included the prices paid at a large meteorite auction, as well as two records of many sales, but excluded all abnormal figures. He was the first to fully emphasize the fact that a large specimen is worth far less per gram than a small one of the same fall. However, he greatly overestimated this variation in saying, in effect, that an increase of sixteen-fold in weight deserved a decrease to one eighth the gram price. This would make a 16-pound piece worth only twice as much as a 1-pound piece of the same fall.

Present Factors.—In using the Ward Collation, the writer, in common with most exchangers, found it of great value, but as often lacking because of the numerous meteorites commercially quoted during the intervening eight years. In making a 1912 collation for personal use, it seemed worth while to check it carefully throughout and publish with certain observations.

The following arrangement of the main elements of meteorite values, attempts only to roughly indicate the order of their importance. The first factor may make a difference of several hundred-fold in the gram price, the second usually five to ten-fold, and rarely much more. The remaining factors generally involve lesser variations.

Essential Factors.

1. Present known weight.
2. Weight of specimen offered.
3. Number of owners.
4. Group weight.
5. Observation of fall.

[5] "Values of Meteorites: Relative and Individual," *The Mineral Collector*, Vol. XI., No. 7, pp. 97–115, New York.

Occasional Factors.

6. Area of slice offered.
7. Phenomenal variation between individual specimens.
8. Distinctness of structure.
9. Missing portions.
10. Historical interest.

1. *Present Known Weight.*—Wülfing distinguishes between the original weight and the present known weight among recorded owners. After the original weight is announced, usually the only important loss is by sawing, etc.; hence the portions held by unknown owners should not be ignored. In general the present weight may be approximated by subtracting from the original weight, a loss of 10 per cent. to 30 per cent., according to the extent and manner of division.

Evidently we have here supply versus demand in its simplest aspect. Thus, Canyon Diablo and Toluca are at one end of the list, with many tons distributed, and respectively offered at 3 cents and 4 cents per gram, or only double the price of silver. Omitting Adalia and one or two others of which only a few grams are known, we may take as typical of the most costly meteorites, Angra dos Reis, Barea and Epinal, with an average known weight of 1,000 grams. These bring over $7.00 per gram, or ten times their weight in gold.

2. *Weight of Specimen Offered.*—This variation is based on the high costs of sawing irons, as well as on the consequent loss of one tenth to three tenths of their mass; and finally on the expensive distribution of all kinds of meteorites to the most limited, yet widely scattered, of markets. While this principle is generally recognized in practice, the fact that it is second only in importance to the weight of the fall, is frequently overlooked. Although excluded by Wülfing, if allowance is not made for this element, his system often becomes misleading in individual transactions. Its relative importance is shown by many sales. Thus, Canyon Diablo, of which fifteen to twenty tons have been distributed, brings in 100 gram pieces 3 cents per gram, and in 100 kilogram pieces three tenths cent per gram, or $3.00 per kilogram. That is, a thousand fold

increase in weight means a reduction to one tenth of the per gram price. At rare intervals greater extremes of this price variation are shown by wholly abnormal and unstable quotations.

In the case of iron localities affording a few hundred to a few thousand kilos, a ratio of price variation of about 8:1 will be typical where the weight variation is 1:1,000. This is roughly illustrated in the table below by the recently found Amalia, a fall identical with the original Mukerop.

Ordinary Prices.		Exceptional Prices.	
Highest.	33 Per Cent. Decrease.	50 Per Cent. Further Decrease.	60 Per Cent. Final Decrease.
Very thin slices of about 30 grams (0.03 kilo)	Thin slices of about 300 grams (0.3 kilo)	Thick slices of about 3000 grams (3 kilos)	Very thick slices or end-pieces of about 30,000 grams (30 kilos)
6 cents per gram ($60.00 per kilo). Price, $1.80	4 cents per gram ($40.00 per kilo). Price, $12.00	2 cents per gram ($20.00 per kilo). Price, $60.00	0.8 cent per gram ($8.00 per kilo). Price, $240.00

One universal tendency is for the price variation to lessen directly with the decrease in total weight, so that in meteorites totaling less than 1,000 grams, the price variation may not exceed 3:2 in a weight variation of 1:10. There are two elements in price variations between 30 and 30,000 grams. The first element is difference in weight and the second is difference in thickness. If we eliminate the latter, there is less price variation. Thus an iron slice of 3,000 grams, measuring $20 \times 20 \times 1$ cm. thick, is worth nearly as much per gram as a 30-gram piece measuring $2 \times 2 \times 1$ cm. This is partly because the relative cost of sawing a large slice is more than for a small one. Stony meteorites have a smaller ratio of price variation, generally ranging below 4:1, in a weight variation of 1:1,000, because the costs of sawing are less than for irons. Further, single stones of over 20 kilos are somewhat rare and are in demand as complete individuals. It may be further noted that collectors differ as to whether aerolites are better sawed or broken. The latter method of division avoids waste of material and labor costs, and affords a broader fractured surface; at the same time it does not prevent polishing a small face if desired. In falls dis-

tinguished by an abundance of small complete individuals, their gram price is somewhat lower than that for slices, because of the sawing cost. Examples are Canyon Diablo, Toluca, Estherville, Mocs, Pultusk, Holbrook, etc.

3. *Number of Owners.*—As pointed out by Cohen, this, to a buyer, is secondary to the number of those who might part with some of their holdings. Omitting irons seen to fall and localities of which the original weight was much greater than the present recorded weight, the market values of the following are more than three times those of Wülfing: Barea, Bendego, Daniel's Kuil, Djati Pengilon, Elbogen, Emmitsburg, Epinal, Juncal, Krähenberg, La Caille, Molina, Nulles, Petropavlovsk, Red River, Tieschitz and Wold Cottage. For the preceding list, the average number of recorded owners is 21, but only one or rarely two owners of each fall have an excess over their own requirements. Wülfing's low price, based partly on the number of owners, is here in great measure explained. Nevertheless the disposer of a meteorite, in evaluating it, will consider the likely exchangers, lowering his price according to the number of those who already possess nearly as much as their probable requirement.

On the other hand some of the cheapest meteorites in the market are held at first by some one dealer whose policy is to sell at a figure which will dispose of his stock within a few years. In nearly all cases where a locality is so controlled, the price is lower than the Wülfing value, and far lower than if held by a large institution which has parted with little or none. The high exchange offers which the institution receives, even though uninvited, tend to elevate the trade price until their exchange policy loosens. Many of the highest ruling prices are largely due to such influences. Further on this is clearly shown in a comparative analysis of the Wülfing values and the trade prices collated by Cohen.

This factor of available weight, so dependent on personal inclination, is the most uncertain of the essential elements, the fall being almost unobtainable where it is preserved entire as municipal or church property. Between the extremes cited lie those meteorites held in public meteorite collections, where the policy is nearly

always against the preservation of a fall in its entirety. For the purpose of study, a broad slice or polished end piece is quite as valuable as a large mass of iron.

4. *Group Weight.*—Stony meteorites are classified in groups according to their petrographic structure and composition; irons according to their crystallization. Wülfing gives this second position among the factors of value. He calculates the total weight of each group, giving to individual falls a value influenced by the group weight.

5. *Observation of Fall.*—This factor is placed eighth and last by Wülfing. His final exclusion of such a factor constitutes another limitation of his formula, as may be seen by a comparison of actual selling prices with his theoretical values. Of about 300 known irons, only nine have been seen to fall. Comparing only these siderites seen to fall and listed by Wülfing, which have been retailed: Agram, Charlotte, Braunau, Rowton, Mazapil, we find that Wülfing's theoretical value averages for these five falls 55 cents per gram, whereas the last quoted selling prices averaged $4.71 per gram, showing that sellers have rated irons seen to fall at more than eight times the figures that Wülfing accords them.

Four siderolites seen to fall, Estherville, Lodran, Mincy and Veramin, which are collated by Cohen at an average of $3.06, are estimated by Wülfing at an average of $4.42. This comparison is quite inconclusive because of the uncertainty as to the location of a large portion of the original weight of Lodran. As Wülfing estimates it by the present recorded weight, its value is enormously inflated ($15.71), thus nullifying the results. Eliminating Lodran, the remaining three are averaged by Wülfing at $1.99 and by Cohen at $6.61, showing that siderolites seen to fall are estimated by Wülfing at less than one third their market value.

But when we examine the aerolites, we find that out of nearly 400 known stones, only about one twelfth have not been seen to fall. The following ten aerolites not seen to fall, are the only ones quoted by dealers and estimated by Wülfing: Goalpara, Tomhannock Creek, Waconda, Prairie Dog Creek, Long Island, Salt Lake City, McKinney, Bluff, Pipe Creek and Minas Geraes. The average of the

last quoted medium trade prices, is 75 cents, and their average Wülfing price is $2.20. Thus on stones not seen to fall, Wülfing estimates about three times the market value.

6. *Area of Slice.*—According to Cohen, a section of relatively large exhibition area is of more value per gram than a thicker piece of the same weight. Of two pieces of the same weight, the one having the larger exhibition surface will be chosen, as better illustrating the variation in structure, crystallization and included minerals, besides making a more impressive display. However, most 1912 catalogues show no apparent difference in the price per gram because of differences in thickness. While there is little advantage in a slice of iron 20 to 30 cm. broad being more than 1 cm. thick, some siderolites and aerolites require a greater thickness because of their friability. Quite apart from the relative desirability of two pieces of the same weight but of differing exhibition area, is the large item of cost, since a thin slice costs proportionately more per gram for sawing and wastage than a thick slice.

7. *Phenomenal Variation between Individual Specimens.*—Interesting differences between individual slices or masses of the same fall are often seen. In aerolites, one fragment or slice may (1) have much more crust than another; (2) it may show a slickensided surface; (3) primary and secondary crust formed before and after exploding; (4) radial lines of fusion flow on the front, with thicker overflow on back; (5) brecciation, etc. In irons, one slice may (1) rarely show hieroglyphic characters and often nodules of included iron compounds; (2) twinning; (3) a flowage of the usually straight Widmanstätten figures; (4) on the exterior deep pitting, or fluidal lines; (5) more commonly, marked octahedral cleavage. Such features increase the value of one piece over that of another of the same weight and fall which is less interestingly marked. An extreme case is Canyon Diablo, valued at 3 cents per gram. When showing diamonds (of no commercial value), the price has exceeded 30 cents per gram.

8. *Distinctness of Structure.*—Other things being equal, beautifully crystallized irons and stones of striking chondritic structure, are prized higher than those in which the crystallization is clouded or the structure quite indistinct.

9. *Missing Portions.*—This factor concerns very few meteorites, but where formerly unobtainable pieces are secured, they naturally cause a depreciation in the price. Such a drop is sometimes discounted where the ultimate availability of the missing portion is assured.

10. *Historical Interest.*—Comparatively few falls are affected in value by this element. Where a meteorite has fallen near a town and has been preserved as an object of civic pride for many years, as in the case of Krähenberg, Elbogen and Ensisheim, its value is greatly enhanced, since it is practically unobtainable. Again, when it has been worshiped or venerated by primitive or even civilized peoples, as in the case of Wichita, Durala, Kesen and many others, its value is slightly increased. Finally, the one or two prehistoric meteorites (Casas Grandes, Anderson, etc.) have a somewhat higher value because of their ethnological interest.

The 1912 Collation.—Leaving the general discussion of values, we may examine actual prices as shown in the following table. The totals of 241 falls collated by Cohen and 366 by Ward, are here increased to 465. To facilitate comparisons with former periods, the collating rules of Ward are observed:

Only specimens under 400 grams weight are included.

Original sales by the finder are excluded.

The catalogue price *per gram* of a fall is determined by dividing the total price of the catalogued specimens by the total weight.

The following prices are, in the opinion of the writer, abnormally high and often erroneous. They were excluded from the collation because based on comparatively insignificant material, generally fragmentary. They are more than 50 per cent. higher than the next lower price collated for the same fall: Benares, $3.00; Bischtübe, 44 cents; Bjurböle, 59 cents; Bluff, 15 cents; Brenham, 30 cents and 40 cents; Canyon Diablo, 19 cents; Charcas, 37 cents; Cosby's Creek, 25 cents; Crab Orchard, 25 cents; Doña Inez, 27 cents; Estacado, 12 cents; Estherville, 44 cents; Hessle, 76 cents; Homestead, 36 cents; Kernouvé, $1.00; Kesen, 73 cents; Kuleschovka, $6.00; Medwedewa, 60 cents; Mincy, 31 cents; Nelson County, 63 cents; Ness County, 16 cents; Nocoleche, 75 cents;

Saline, 79 cents; Trenton, 23 cents and 42 cents; Wichita, 35 cents; Zaborsika, $8.00; Zacatecas, 78 cents.

No prices are omitted from the collation because of being too low. The following however are some of those which are more than 50 per cent. lower than the next higher price or Wülfing's value, where no other price is given. In the writer's opinion these figures are too low. Nearly all are for fragments of a few grams. Bath, 20 cents; Black Mt., 33 cents; Bustee, $1.00; Copiapo, 33 cents; Dalton, 6 cents; El Capitan, 11 cents; Harrison Co., $1.00; Ibbenbühren, $1.50; Le Pressoir, $1.25; Mantos Blancos, 38 cents; Motta di Conti, 38 cents; Nammianthal, 75 cents; Orvinio, $1.20; Pipe Creek, 17 cents; Pirgunje, $1.50; Reed City, 13 cents; Richmond, $1.20; St. Denis Westrem, $1.00; Salt River, 91 cents; Uden, $2.00; Yatoor, 33 cents. The lowest Toluca price is based on several slices. One small complete mass listed in the same catalogue at 1 cent per gram is excluded. The iron-shales resulting from the oxidation of the Canyon Diablo and Augustinovka irons are omitted. The Wülfing (1897) exchange values of the following falls are not quoted, as their subsequent re-classification probably gave them new group weights: Barratta, Carlton, Eagle Station, Crab Orchard, Dakota, Imilac, Kendall County, Mejillones, Salt River, Shingle Springs, Summit and Zaborzika. Wülfing's value for Fisher is omitted, being erroneous because based on incomplete data.

Only seven dealers issue catalogues. Two American and one European publication have names and prices printed and are not annual, being dated 1912, 1907 and 1908 respectively; two European have names printed but prices written in, while two small European lists were merely typewritten.

ROSE-TSCHERMAK-BREZINA SYMBOLS.[6]

A	Angrite	Cco	Ornansite
a	veined	Cek	Crystalline Enstatite-Anorthite Chondrite
Am	Amphoterite	Cg	Gray Chondrite
b	breccia-like	Cha	Chassignite
Bu	Bustite	Chl	Chladnite
C	Chondrite	Co	Orvinite
c	spherulitic	Db	Ataxite, Babb's Mills group
Ccn	Ngawite		

[6] Dr. Aristides Brezina, PROC. AM. PHIL. SOC., Vol. 53, No. 176, pp. 211 to 247.

PROC. AMER. PHIL. SOC., LII. 211 P, PRINTED OCT. 3, 1913.

Dc	Ataxite, Cape group
Dm	Ataxite, Muchachos group
Dn	Ataxite, Nedagolla group
Dp	Ataxite, Primitiva group
Ds	Ataxite, Siratic group
Dsh	Ataxite, Shingle Springs group
Eu	Eukrite
f	fine
ff	finest
gg	broadest
H	Normal Hexahedrite, not granular
Ha	Granular Hexahedrite
Ho	Howardite
ho	Howarditic
i	intermediate
K	Carbonaceous Chondrite
k	crystalline
Lo	Lodranite
M	Mesosiderite
m	medium
Mg	Grahamite
n	Netschaevo group
O	Octahedrite
Obc	Brecciated Octahedrite, Copiapo group
Og	Broad Octahedrite
Pa	Pallasite, Albach group
Pi	Pallasite, Imilac group
Pk	Pallasite, Krasnojarsk group
Pr	Pallasite, Rokicky group
Ro	Rodite
s	black
Si	Siderophyre
U	Ureilite
w	white
z	Zacatecas group
zg	N'Goureyma group

The critical scrutiny to which theoretical prices are usually subjected should not be discarded in considering the following trade figures. They are not reproduced here as being true value indices in all cases, and should therefore be analyzed before accepting them as a guide in any important transfer.

The total Wülfing exchange values of 248 falls having both Wülfing and 1912 values, afford the factor 3.1904+, when divided into the total of the corresponding medium 1912 values in the present collation. Hence the first column of figures is Wülfing's theoretical exchange index multiplied by the approximate factor 3.2.[7] Wherever Wülfing gives two figures as of equal probability, the mean is employed. If he prefers one of two given, the preferred only is used. Where he places both values within brackets as doubtful, both are omitted.

The second column of figures gives the 1899 medium market prices.

The third column gives the 1904 medium market prices.

The fourth column gives the lowest 1912 market prices.

The fifth and last column gives the medium 1912 market prices.

The highest 1912 price of any fall may be roughly calculated by comparing its lowest with its average price for 1912.

Prices are per gram in dollars, counting M4/=4/—=$1.00.

[7] The approximate factor used by Cohen was 3.1 cents (13 pfgs.).

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Abert Iron; locality?	Om	1.63	—	—	2.69	2.69
Adargas	Om	—	—	.18	—	—
Admire	Pr	—	—	.39	.09	.20
Agen	Cia	.74	.89	1.39	.54	.77
Agram	Om	.26	—	10.00	—	—
Ahumada	Pr	—	—	—	.24	.24
Aigle, see L'Aigle.						
Alais	K	4.48	3.62	4.00	7.00	7.00
Alastoewa, see Djati Pengilon.						
Albacher Mühle, see Bitburg.						
Albareto	Cc	1.60	—	1.75	2.50	2.50
Aldsworth	Cga	2.75	—	1.17	—	—
Aleppo	Cwb	3.55	.37	.52	—	—
Alessandria	Cga	2.02	—	.75	—	—
Alexejevka, see Bachmut.						
Alfianello	Ci	.32	.16	.14	.07	.11
Algoma	Om	—	—	1.00	—	—
Allegan	Cco	—	—	.17	.18	.20
Amalia, see Mukerop.						
Amana, see Homestead.						
Ambapur	Cck	—	1.06	.66	—	—
Anderson	Pk	—	—	6.50	—	—
Andover	Cc	—	—	1.61	—	—
Angers	Cwa	3.46	—	2.62	—	—
Angra dos Reis	A	15.72	6.00	8.00	—	—
Antifona, see Collescipoli						
Apoala	Of	—	—	.23	—	—
Apt	Cga	1.60	—	1.08	1.25	1.25
Arispe	Ogg	—	—	.10	.10	.12
Arlington	Om	—	.95	.46	.24	.28
Arva, see Magura.						
Asheville, see Black Mountain and Bairds Farm.						
Assisi	Cc	1.60	1.00	.93	.68	1.06
Aubres	Bu	16.93	—	2.50	—	—
Auburn	H	.80	—	.88	1.56	1.56
Augustinovka	Of	—	.44	.47	.25	.26
Aumières	Cwa	1.60	—	2.09	1.48	2.24
Ausson	Cc	.64	1.15	.57	.56	.68
Avilez	Cc	3.55	4.55	—	—	—
Babb's Mill	Db	.13	.70	.46	.34	.34
Bachmut	Cw	1.60	1.00	1.02	1.00	1.00
Bacubirito	Off	—	—	.22	.25	.25
Bahia, see Bendego.						
Bairds Farm	Om	.74	—	.55	.33	.33
Bald Eagle	Om	—	—	1.02	—	—
Bali Kamerun	Cs	—	—	—	6.00	6.00
Ballinoo	Off	—	.15	.22	.12	.18
Bandong	Ro	1.28	—	.75	—	—
Barbotan	Cga	.74	1.13	.71	.56	.93
Barea	M	1.28	—	7.50	—	—

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Barranca Blanca	Obz	—	—	.30	1.00	1.00
Barratta	Cgb	—	—	.22	.15	.15
Batesville, see Joe Wright.						
Bath	Ccb	.74	.35	.18	.20	.34
Bath Furnace	Cia	—	—	.29	.31	.31
Beaconsfield, see Cranbourne.						
Bear Creek	Of	.22	—	.78	.84	.84
Beaver Creek	Cck	1.60	.50	.28	1.00	1.00
Bella Roca	Of	.35	.24	.22	.14	.18
Benares	Cc	.96	3.00	2.07	1.89	1.89
Bendego	Og	.03	.22	.16	.08	.11
Berlanguillas	Cia	1.60	—	2.27	—	—
Bethlehem	Cck	—	—	6.50	10.00	10.00
Beuste	Cgb	1.60	—	2.00	—	—
Bialystock	Ho	6.53	—	.65	—	—
Bielokrynitschie	Cib	2.69	—	.73	.66	.78
Billings	Og	—	—	—	.20	.20
Bischtübe	Og	.26	—	.34	.10	.10
Bishopville	Chla	3.46	2.35	1.75	4.88	4.88
Bishunpur	Cs	3.97	—	3.00	—	—
Bitburg (unmelted)	Pa	—	2.40	—	—	—
Bitburg (melted)	Pa	—	—	.14	.12	.12
Bjurböle	Cca	—	—	.08	.08	.12
Black Mountain	Og	1.22	1.06	1.53	.33	.33
Blansko	Cga	2.62	—	4.75	—	—
Bluff	Ckb	.32	.15	.07	.05	.05
Bocas	Cw	—	—	5.00	—	—
Bohumilitz	Og	.19	.25	.34	.21	.31
Bois de Fontaine, see Charsonville.						
Bonanza, see Coahuila.						
Borgo San Donino	Cho	1.70	—	.75	.50	.50
Bori	Cia	1.02	1.09	.64	—	—
Borkut	Cc	1.22	1.25	.99	.80	.80
Borodino	Cgb	3.55	—	—	7.14	7.14
Botschetschki	Cg	2.75	—	2.00	—	—
Brahin	Pr	—	1.42	.80	—	—
Braunau	H	.26	.87	.78	.73	1.12
Breitenbach	Si	—	—	.35	.38	.38
Bremervörde	Ccb	.74	.95	1.10	1.28	1.28
Brenham	Pk	.10	.20	.12	.06	.11
Bridgewater	Of	.90	.39	.25	1.20	1.20
Bückeberg, see Obernkirchen.						
Burlington	Om	.45	.42	.36	.52	.53
Buschhof	Cwa	.96	2.50	.68	1.00	1.00
Bustee	Bu	9.89	—	—	1.00	1.00
Butcher Iron, see Coahuila.						
Butler	Off	—	.37	.24	.25	.25
Butsura	Ci	.45	—	.58	—	—
Cabarrus County, see Monroe.						

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1859.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Cabezzo de Mayo	Cw	1.25	2.55	.75	4.00	4.00
Cambria	Of	.45	.40	.36	.74	.74
Campo del Cielo	Ds	.06	.97	.91	.47	.47
Canellas	Ci	1.02	—	1.75	—	—
Cangas de Onis	Cgb	.93	1.02	.73	1.00	1.00
Canyon City	Og	—	—	—	.20	.37
Canyon Diablo	Og	.03	.10	.07	.03	.03
Canton	Ogg	—	—	.15	—	—
Cape Girardeau	Cc	1.63	—	.95	2.00	2.00
Cape of Good Hope	Dc	.58	.62	.45	.41	.41
Carlton	Off	—	.24	.16	.10	.17
Carthage	Om	.13	.22	.29	.19	.28
Casas Grandes	Om	—	—	—	.13	.13
Casey County	Og	.93	—	.65	1.37	1.37
Castalia	Cgb	.74	—	.82	.75	.87
Castine	Cwa	—	—	4.16	2.00	2.00
Central Missouri	Ogg	—	—	.16	—	—
Cereseto	Ccb	1.22	1.16	1.25	—	—
Chandakapur	Cib	.99	—	.62	—	—
Chantonnay	Cgb	.67	.56	.38	.47	.54
Charcas	Om	.10	—	.17	.19	.21
Charlotte	Of	.93	—	1.60	3.52	3.52
Charsonville	Cga	.74	1.14	.65	.49	.66
Chassigny	Cha	7.87	—	2.93	7.00	7.00
Château Renard	Cia	.58	.61	.48	.42	.58
Chesterville	Ds	1.60	.35	.19	—	—
Chulafinnee	Om	.35	.55	.34	—	—
Chupaderos	Of	—	.41	.22	.05	.10
Claiborne, see Lime Creek.						
Clarac, see Ausson.						
Cléguérec, see Kernouvé						
Cleveland (Lea Iron)	Om	.16	—	.30	.30	.30
Coahuila (exact loc.?)	H	.06	—	—	.03	.03
Coahuila (Sancha Estate, Saltillo or Couch Iron)	H	.06	.20	.15	.14	.15
Coahuila (Fort Duncan)	H	.06	.20	.09	.07	.09
Coahuila (Butcher Irons from Bonanza and Desert of Mapimi)	H	.06	.12	.11	.08	.08
Cooke County, see Cosby's Creek.						
Cold Bokkeveldt	K	1.86	2.25	1.38	1.33	1.44
Colfax	Om	—	.52	.40	.98	.98
Collescipoli	Cc	1.12	.75	.88	.63	.63
Concepcion, see Adargas.						
Coon Butte	Cib	—	—	—	.59	.59
Coopertown	Om	.26	—	.42	1.00	1.00
Copiapo	Obc	1.22	.50	1.20	.33	.33
Cosby's Creek	Og	.16	.30	.15	.10	.11
Costilla Peak	Om	.38	—	.14	.11	.14
Cowra	Off	—	2.10	2.00	—	—
Crab Orchard	Mg	—	.12	.12	.11	.12

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Cranbourne (Beaconsfield)	Og	—	.17	.10	.11	.11
Cranbourne (Melbourne)	Og	.03	.22	.23	.05	.06
Cross Timbers, see Red River.						
Cuernavaca	Of	—	—	.12	.11	.21
Cynthiana	Cg	1.22	—	.80	1.00	1.00
Dakota	Ogg	—	—	.40	.60	.60
Dalton	Om	.19	.57	.27	.06	.23
Dandapur	Cia	.93	—	—	1.00	1.00
Daniel's Kuil	Ck	1.57	—	3.00	5.00	5.00
Danville	Cga	2.34	—	3.00	6.00	6.00
Deep Springs	Db	—	—	.26	.30	.30
Denton County	Om	.54	—	.80	1.17	1.17
Descubridora	Om	.13	—	.15	.11	.12
Dhulia	Cwa	—	—	5.50	—	—
Dhurmsala	Ci	.45	.25	.16	.10	.20
Djati Pengilon	Ck	.22	2.00	1.00	.97	.97
Dolgovoli	Cw	2.69	—	1.13	1.00	1.00
Dona Inez	M	.58	.19	.18	.12	.15
Dores dos Campos Formosus	Cwa	—	—	—	.40	.40
Doroninsk	Cgb	1.82	2.50	1.50	—	—
Drake Creek	Cwa	.74	—	.65	.75	.75
Durala	Cia	.74	—	—	1.25	1.25
Duruma	Cia	2.02	1.07	2.00	4.00	4.00
Eagle Station	Pr	—	.49	.39	.48	.50
Ekaterinoslav, see Mordvinovka.						
Elbogen	Om	.13	.75	.85	1.00	1.15
El Capitan	Om	.51	.24	.13	.11	.11
Elgueras, see Cangas de Onis.						
Elm Creek	Cco	—	—	—	.22	.22
Emmitsburg	Om	1.60	—	1.24	5.00	5.00
Ensisheim	Ckb	.35	.62	.74	.92	.96
Epinal	Cc	2.62	10.62	—	—	—
Erghco	Ckb	—	—	.26	.15	.19
Erxleben	Ck	.99	—	.84	1.00	1.00
Estacado	Cka	—	—	—	.05	.05
Estherville	M	.16	.19	.14	.13	.16
Farmington	Csa	.35	.19	.09	.08	.13
Favars	Ci	2.02	—	3.25	—	—
Fayette County, see Bluff.						
Fisher	Cia	—	—	.30	.35	.35
Forest	Ccb	.26	.23	.12	.08	.15
Forsyth	Cwa	.74	—	.87	2.00	2.00
Forsyth County	Dn	—	—	.19	.21	.21
Fort Duncan, see Coahuila.						
Fort St. Pierre	Om	.42	.44	.52	.59	.76
Franceville	Om	—	—	—	.10	.10
Frankfort	Ho	7.30	—	4.00	4.13	5.56

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Futtehpur	Cwa	.96	—	1.00	—	—
Ghambat	Cia	—	1.04	—	—	—
Gilgoin	Ck	—	—	.18	.11	.11
Girgenti	Cwa	.96	1.00	1.23	2.07	2.07
Glorieta Mountain	Om	.13	.25	.20	.12	.12
Gnadenfrei	Cc	1.60	5.00	—	1.00	1.00
Gnarrenburg, see Bremervörde.						
Goalpara	U	5.63	—	3.00	—	—
Goamus, see Mukerop.						
Grand Rapids	Of	.35	.16	.13	.13	.19
Great Fish River	Of	1.70	—	—	2.50	2.50
Grosnaja	Cs	.96	3.25	2.07	1.00	1.00
Gross-Liebenthal	Cwa	.93	1.75	.89	.50	.88
Grüneberg	Cga	2.02	—	1.00	—	—
Guareña	Ck	.58	—	1.50	—	—
Hainholz	M	.45	—	.35	.38	.38
Harrison County	Cho	2.43	—	—	1.00	1.00
Hartford (Linn County) see Marion.						
Heredia	Ccb	2.02	—	—	3.50	3.50
Hessle	Cc	.45	.89	.44	.38	.42
Hex River	H	.35	.14	.17	.50	.50
Holbrook	Cck	—	—	—	.09	.09
Holland's Store	Ha	.93	—	.37	—	—
Homestead	Cgb	.22	.15	.15	.10	.15
Honolulu	Cwa	.96	1.31	1.18	2.00	2.00
Hopper	O	—	—	1.20	—	—
Hraschina, see Agram.						
Huejuquilla, see Chupaderos.						
Hungen	Cga	4.70	—	4.00	—	—
Hvittis	Cck	—	—	—	.98	.98
Ibbenbühren	Chl	4.35	—	1.50	1.50	1.50
Ilimaë	Om	.38	—	—	.25	.25
Imilac	Pi	—	.34	.13	.17	.19
Inca, see Llano del Inca.						
Indarch	Kca	1.60	2.32	2.17	.89	.89
Independence, see Kenton County.						
Indian Valley	Ha	—	—	—	.74	.74
Indio Rico	Ck	—	—	—	2.50	2.50
Iquique	Dc	2.43	—	.90	—	—
Iredell	H	—	—	—	1.49	1.49
Ivanpah	Om	.26	—	.65	.14	.14
Jackson County	Om	1.63	—	—	3.03	3.03
Jamestown	Of	1.28	.36	.28	.43	.62
Jamyscheva, see Pavlodar.						
Jelica	Am	.96	.37	.38	1.50	1.50
Jenny's Creek	Og	.64	.66	.53	.30	.39
Jerôme	Cck	—	—	.60	.20	.20
Jewell Hill	Of	.45	1.57	.77	.75	.75
Joel's Iron	Om	.74	1.70	—	1.67	1.67
Joe Wright Mountain	Om	.19	.37	.24	.29	.29

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Jonzac	Eu	1.89	—	2.25	—	—
Juncal	Om	.16	.96	.52	—	—
Juvinas	Eu	.58	1.11	1.80	.49	.53
Kaande, see Oesel.						
Kaba	K	2.08	—	2.74	—	—
Kakangarai	Stone	—	—	1.86	—	—
Kansada, see Ness County.						
Karakol	Cw	2.75	—	2.00	—	—
Karand, see Veramin.						
Kendall County	Hb	—	.26	.22	.18	.25
Kenton County	Om	.16	.16	.09	.06	.07
Kermichel	Ck	—	—	—	1.48	1.48
Kernouvé	Cka	.35	.67	.51	.42	.46
Kesen	Ccb	.93	.52	.26	.13	.18
Khairpur	Ck	.58	—	1.71	1.67	1.67
Kilbourn	Cga	—	—	—	4.67	4.67
Kingston	Om	—	—	—	.40	.40
Klein Menow	Cck	1.60	1.30	—	1.23	1.23
Klein Wenden	Ck	.93	—	.74	—	—
Knyahinya	Cg	.19	.17	.13	.08	.13
Kodaikanal	Obk	—	—	—	.60	.60
Kokomo	Dc	2.02	—	—	4.31	4.31
Kokstad	Om	.51	.50	—	—	—
Krähenberg	Cho	.99	—	3.00	—	—
Krasnojarsk, see Medwedewa.						
Krawin, see Tabor.						
Kuleschovka	Cwa	.74	—	—	1.00	1.00
La Baffe, see Epinal.						
La Bécasse	Cw	2.75	—	1.04	—	—
Laborel	Cib	—	1.25	1.00	—	—
La Caille	Om	.06	.64	.78	.79	.79
La Grange	Of	.35	—	.37	.60	.60
L'Aigle	Cib	.74	.39	.29	.18	.20
Lancé	Kc	.54	—	1.30	.90	.95
Lançon	Cia	—	1.06	.82	.82	.91
La Primitiva	Dp	1.09	1.06	—	—	—
Lasdany, see Lixna.						
Laurens County	Of	—	—	.90	—	—
Lea Iron, see Cleveland.						
Leighton	Cgb	—	—	—	2.86	2.86
Lenarto	Om	.16	.50	.23	.25	.29
Le Pressoir	Cc	2.02	4.25	2.52	1.25	2.12
Les Ormes	Cw	7.87	—	4.00	—	—
Lesves	Cw	—	1.32	1.13	—	—
Le Teilleul	Ho	9.89	—	3.00	—	—
Lexington County	Og	.54	—	.25	.27	.27
Lick Creek	H	.99	1.25	—	—	—
Lime Creek	H	.22	.75	.24	.21	.21
Limerick	Cgb	.51	—	1.19	.83	.83
Linn Co., see Marion.						
Linnville	Db	7.65	—	1.50	6.00	6.00
Lion River	Of	.26	.64	.38	.38	.38

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Lissa	Cwb	.58	1.22	.97	—	—
Little Piney	Cc	—	—	—	5.00	5.00
Lixna	Cga	.74	1.56	.81	1.00	1.00
Llano del Inca	M	.74	.14	.13	.04	.07
Lockport, see Cambria.						
Locust Grove	Ds	—	.27	.15	.38	.38
Lodran	Lo	15.71	5.65	3.65	—	—
Long Island	Cia	.32	.11	.09	.08	.10
Losse, see Barbotan.						
Losttown	Om	.54	.34	.26	—	—
Lucky Hill	Om	.77	—	—	1.00	1.00
Luis Lopez	Om	—	—	.28	.25	.27
Macao	Cia	1.22	—	1.75	2.86	2.86
Macquaire River	M	—	—	—	.91	.91
Madoc	Of	.22	1.25	—	—	—
Maêmê	Cia	—	.59	.63	1.50	1.50
Magura	Og	.13	.15	.09	.10	.10
Mainz	Cia	—	1.27	1.10	—	—
Manbhoom	Am	2.62	2.52	2.10	2.14	2.55
Mantos Blancos	Of	.99	—	—	.38	.95
Marion	Cwa	.67	.55	.30	.30	.37
Marjahlatti	Pi	—	—	—	.44	.44
Mart	Off	—	—	.57	—	—
Mauerkirchen	Cw	.99	1.84	.79	—	—
Mazapil	Om	.77	—	3.40	5.59	5.59
McKinney	Cs	.86	.17	.16	.08	.12
Medwedewa	Pk	.10	.47	.22	.24	.25
Mejillones	Mg	—	—	.20	1.00	1.00
Menow, see Klein Menow.						
Merceditas	Om	.19	.31	.35	.25	.29
Mern	C	—	—	—	.71	.71
Mezö-Madaras	Cgb	.45	1.75	.72	.31	.31
Mhow	Ci	3.55	—	.85	—	—
Midt Vaage, see Tysnes.						
Mighei	K	1.60	3.00	1.79	1.24	1.25
Mikenskoi, see Grosnaja						
Milena	Cw	1.60	1.45	.97	1.00	1.00
Minas Geraes	Cwa	2.18	—	—	1.82	1.82
Mincy	M	.26	.17	.17	.14	.17
Misshof	Cc	1.22	.95	.64	.64	.67
Misteca	Om	.22	.35	.14	.11	.18
Mocs	Cwa	.26	.11	.08	.08	.10
Modoc	Cwa	—	—	—	.40	.41
Molina	Cgb	.35	—	2.85	2.50	2.50
Monroe	Cga	.86	.67	.69	.90	.95
Mooranoppin	Ogg	—	.95	.62	—	—
Mooresfort	Ccb	.96	1.85	1.13	2.00	2.00
Mordvinovka	Cw	1.31	—	—	1.25	1.85
Morristown	Mg	—	.20	.14	.12	.21
Motta di Conti	Cc	1.28	—	.57	.38	.38
Mount Browne	Cc	—	—	—	1.47	1.47
Mount Joy	Ogg	.26	.05	.10	.06	.08
Mount Stirling	Og	—	.22	.17	.17	.17
Mount Vernon	Pk	—	—	—	.36	.36

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Muchachos, see Tucson.						
Mukerop (exact loc. ?).	Off	—	—	.10	.10	.12
Mukerop (Amalia Farm)	Off	—	—	—	.04	.04
Mukerop, (Goamus)...	Off	—	—	—	.06	.06
Mungindi	Off	—	.25	.19	.15	.19
Muonionalusta	Of	—	—	—	.75	.75
Murfreesboro	Om	.45	1.27	.32	1.27	1.27
Murphy	H	—	—	.22	.14	.14
Nagaya	K	2.08	1.85	—	1.50	1.75
Nagy-Vazsony	Om	1.02	—	.70	—	—
Nammianthal	Cca	2.75	—	—	.75	.75
Nanjemoy	Cc	.96	.70	1.25	2.86	2.86
Nejed	Om	.19	—	.33	.11	.11
Nelson County	Ogg	.45	.25	.16	.12	.19
Nenntmansdorf	H	.45	—	.55	—	—
Nerft	Cia	.74	.85	.69	.75	.75
Ness County	Cib	—	.25	.12	.07	.07
Netschaëvo, see Tula.						
New Concord	Cia	.26	.62	.31	.22	.38
Newton County, see Mincy.						
Ngawi	Ccn	5.79	3.84	1.80	—	—
N'Goureyma	Obzg	—	—	—	.33	.33
Niagara	Og	—	—	—	.50	.50
Nobleborough	Ho	15.71	—	3.50	—	—
Nocoleche	Om	—	.60	.25	.28	.39
Novo-Urei	U	5.63	4.00	3.58	2.25	3.12
Nulles	Cgb	.93	—	3.00	—	—
Oakley	Ck	—	—	.14	—	—
Obernkirchen	Of	.35	.65	.37	.75	.75
Ochansk, see Tabory.						
Oesel	Cw	1.89	1.20	1.10	.72	.87
Okniny	Cgb	2.62	—	2.12	1.50	1.50
Old Fork, see Jenny's Creek.						
Orange River	Om	.16	.71	.82	—	—
Orgueil	K	1.28	1.47	.82	.50	.75
Ornans	Cco	3.39	2.50	1.62	4.00	4.00
Oroville	Om	—	—	.44	.22	.22
Orvinio	Co	4.48	1.32	1.69	1.20	2.15
Oscuro Mountains	Og	—	.47	.38	.25	.49
Ottawa	Cho	—	2.75	—	—	—
Pacula	Cwb	4.13	1.09	.74	1.00	2.00
Pallas, see Medwedewa.						
Parnallee	Cga	.35	.40	.51	.34	.52
Pavlodar	Pk	.74	1.15	.90	.64	.66
Pavlovka	Ho	5.79	—	1.08	—	—
Penkarring Rock, see Youndegin.						
Petersburg	Ho	6.62	—	—	10.00	10.00
Petropavlovsk	Om	.58	—	2.29	—	—
Pila, see Rancho de la Pila.						
Pillistfer	Ck	.35	.95	.95	.69	.82

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Pipe Creek	Cka	2.69	.32	.14	.17	.17
Pirgunje	Cwa	3.97	—	—	1.50	1.50
Pittsburg	Ogg	—	—	1.14	—	—
Ploschkowitz	Ccb	—	—	—	10.00	10.00
Plymouth	Om	1.09	.24	.18	.18	.26
Politz	Cwa	.96	1.87	1.10	—	—
Powder Mill Creek, see Crab Orchard.						
Prairie Dog Creek	Cck	5.12	.60	—	—	—
Prascoles, see Zebrak.						
Primitiva, see La Primitiva.						
Pultusk	Cgb	.19	.07	.05	.05	.07
Puquios	Om	.35	.65	.57	.57	.57
Putnam County	Of	.45	.60	.56	.89	.89
Quenggouk	Cc	.74	1.07	.79	1.00	1.00
Rakovka	Ci	1.22	—	1.43	.80	.80
Ranchito, see Bacubirrito.						
Rancho de la Pila	Om	.19	.64	.17	.18	.18
Rasgata	Ds	.06	—	.32	.42	.59
Red River	Om	.06	.25	.35	.37	.37
Reed City	Om	—	—	.15	.13	.26
Renazzo	Cs	1.12	2.50	1.79	—	—
Rhine Valley	Om	—	—	.25	.50	.50
Richmond	Cck	3.10	—	2.11	1.20	1.20
Rittersgrün, see Steinbach.						
River Brazos, see Wichita.						
Rochester	Cc	3.04	—	2.58	—	—
Roda	Ro	10.14	—	6.00	—	—
Rodeo	Om	—	—	—	.15	.23
Roebourne	Om	—	.20	.14	.10	.13
Rokicky, see Brahin.						
Roquefort, see Barbotan.						
Rosario	Og	—	.92	.38	.29	.29
Rowton	Om	.54	—	3.30	—	—
Ruff's Mountain	Om	.19	.45	.34	.21	.23
Russel Gulch	Of	.58	—	.47	.96	.96
Sacramento Mountains	Om	—	—	.11	.08	.08
Saint Denis Westrem	Cca	3.39	3.12	2.81	1.00	1.00
Saint Francois County	Og	.54	.35	.28	.38	.38
Sainte Genevieve Co.	Of	—	—	.12	.11	.11
Saint Mesmin	Cib	1.57	2.12	.68	1.41	1.41
Saline	Cck	—	—	—	.20	.21
Salles	Cia	.96	—	—	1.00	1.00
Saltillo, see Coahuila.						
Salt Lake City	Cgb	2.75	—	—	1.00	1.00
Salt River	Off	—	—	—	.91	1.45
San Angelo	Om	—	.15	.12	.10	.11
Sancha Estate, see Coahuila.						
Santa Apolonia	O	—	—	—	.05	.05

Name (Locality).	Symbol	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Santa Rosa	Obz	—	—	—	.15	.15
Sao Juliao de Moreira	Ogg	.35	.15	.12	.11	.13
Sarbanovac, see Soko-Banja.						
Sarepta	Og	.35	.32	.51	.31	.31
Saurette, see Apt.						
Savtschenskoje	Cck	5.12	2.50	2.10	—	—
Schönenberg	Cwa	.93	2.36	2.62	—	—
Scottsville	H	.45	.22	.15	.25	.37
Searsmont	Cc	1.60	—	2.98	2.61	2.61
Seeläsgen	Ogg	.45	.27	.17	.13	.16
Segowlee	Ck	.74	—	—	.71	.71
Seneca Falls	Om	.54	—	.61	.73	.73
Senegal River	Ds	.74	.50	1.00	2.00	2.00
Senhadja	Cwa	.74	—	.75	.59	.79
Seres	Cg	.93	—	1.10	—	—
Sevrukovo	Cs	.45	2.20	2.01	—	—
Shalka	Chl	3.46	2.81	—	2.00	2.00
Shelburne	Cg	—	—	—	.25	.46
Shingle Springs	Dsh	—	.75	—	.50	.65
Siena	Ch	1.28	2.31	2.13	—	—
Silver Crown	Og	.45	.34	.26	.22	.24
Siratik, see Senegal.						
Sitathali	Cho	2.14	—	1.00	—	—
Slobodka	Cc	3.97	—	—	3.00	3.00
Smith's Mountain	Of	.93	—	1.08	—	—
Smithville	Og	.26	.13	.11	.09	.09
Soko-Banja	Cc	.45	.46	.41	.29	.38
Ställdalen	Cgb	.45	.79	.65	.40	.49
Stannern	Eu	.74	.51	.34	.39	.40
Staunton	Om	.16	.22	.18	.09	.15
Stavropol	Ck	1.25	—	2.58	1.00	1.00
Steinbach	Si	.58	.51	.46	.34	.36
Stutsman County, see Jamestown.						
Summit	Ha	—	—	—	5.47	5.47
Tabor	Ccb	.74	1.09	1.05	.76	.93
Tabory	Ccb	.26	.25	.27	.14	.20
Tadjera	Ct	3.39	3.00	—	5.00	5.00
Taney County, see Mincy.						
Tazewell	Off	—	.66	.36	.32	.32
Tennant's Iron	Og	—	—	—	.75	.75
Tennasilm	Cca	.93	2.02	1.05	1.00	1.00
Thunda	Om	.26	.45	.20	.15	.17
Thurlow	Of	—	.66	—	—	—
Tieschitz	Cc	.54	2.07	—	—	—
Timochin	Cc	.35	—	.73	.74	.87
Tjabe	Ck	.45	—	.85	1.00	1.00
Toluca	Om	.06	.05	.06	.02	.04
Tomatlan	Cc	—	—	—	1.50	1.50
Tombigbee R. (Jachin)	Ha	—	—	—	.21	.21
Tomhannock Creek	Cgb	1.60	1.95	1.59	.50	2.25
Tonganoxie	Om	—	.32	.16	.22	.22
Torre, see Assisi.						

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Toubil	Om	—	—	—	.71	.73
Toulouse	Cia	2.62	—	—	—	—
Tourinnes-la-Grosse	Cw	1.44	1.50	.87	.88	1.03
Trenton	Om	.19	.31	.17	.14	.14
Trenzano	Cca	.99	.72	.70	.64	.79
Tucson	Dm	.06	.68	.33	—	—
Tula	Obn	2.69	.95	.76	.62	.84
Tysnes	Cgb	.54	.85	.53	.38	.62
Uden	Cwb	4.35	—	2.25	2.00	2.00
Union County	Ogg	1.28	—	1.12	.67	1.06
Utah, see Salt Lake City						
Utrecht	Cca	1.25	2.25	.83	.50	.75
Vaca Muerta	Mg	.35	.59	1.03	.26	.26
Vavilovka	Ro	—	—	—	5.00	5.00
Veramin	M	1.57	6.25	2.81	1.78	2.20
Verkhne Dnieprovsk	Off	—	.87	—	.50	.50
Verkhne Udinsk	Om	.26	.49	.50	.43	.46
Victoria	Om	.22	4.20	.61	2.80	2.80
Vigarano Piave	K	—	—	—	.25	.25
Virba	Cwa	1.63	.50	—	—	—
Vouillé	Cia	.58	1.27	.77	.50	.73
Waconda	Ccb	.58	.47	.19	.12	.15
Wairarapa	C	—	—	—	1.50	1.50
Waldron Ridge	Og	.58	—	.22	—	—
Walker County	H	.22	—	—	.65	.65
Walker Township, see Grand Rapids.						
Warrenton	Cco	4.48	1.80	1.31	4.00	4.00
Welland	Om	.35	.25	.28	.34	.41
Werchne Dnieprowsk, see Verkhne Dnieprovsk.						
Werchne Udinsk, see Verkhne Udinsk.						
West Liberty, see Homestead.						
Weston	Ccb	.58	.60	.45	.50	.54
Wichita	Og	.13	.30	.17	.16	.19
Willamette	Om	—	—	—	.17	.17
Williamstown	O	—	—	—	.19	.22
Winnebago County, see Forest City.						
Wirba, see Virba.						
Wittness	Cc	1.60	2.25	—	2.50	2.50
Wold Cottage	Cwa	.45	—	1.27	2.60	2.60
Yanhuitlan, see Misteca.						
Yardea Station	Om	—	—	2.08	—	—
Yarra Yarra River, see Cranbourne.						
Yatoor	Cc	.74	1.29	—	.33	.33
Youndegin	Og	.10	.34	.17	.12	.14
Zaborzika	Cwa	—	—	—	1.00	1.00
Zacatecas	Obz	—	.40	.24	.07	.19
Zavid	Cia	—	.75	.40	.25	.30
Zebrak	Cc	1.60	2.10	—	—	—

Price Changes.—In comparing the medium prices of 190 falls collated alike by Cohen, Ward and Foote, we find that the average medium price decreased 27.4 per cent. from 1899 to 1904, and increased 18.6 per cent. between 1904 and 1912. Of all the falls collated in 1912, the following 52 have advanced in price more than one half since 1904: Alais, Auburn, Barranca Blanca, Bath, Beaver Creek, Bethlehem, Bishopville, Bridgewater, Cabezzo de Mayo, Cambria, Cape Girardeau, Casey County, Charlotte, Chassigny, Colfax, Coopertown, Cuernavaca, Daniel's Kuil, Danville, Duruma, Emmitsburg, Forsyth, Girgenti, Hex River, Honolulu, Jamestown, Jelica, La Grange, Linnville, Locust Grove, Macao, Maêmê, Mazapil, Mejillones, Mooresfort, Murfreesboro, Nanjemoy, Nocoleche, Obernkirchen, Ornans, Pacula, Putnam County, Rasgata, Reed City, Rhine Valley, Russel Gulch, Saint Mesmin, Scottsville, Senegal River, Victoria, Warrenton, Wold Cottage.

The following seventeen have decreased in price more than one half since 1904: Bischtübe, Black Mountain, Cañon Diablo, Castine, Chupaderos, Copiapo, Cranbourne (Melbourne), Grosnaja, Indarch, Ivanpah, Jerome, Juvinas, Mezö-Madaras, Nejed, Saint Denis Westrem, Stavropol, Vaca Muerta.

Rare Falls Become Less Available.—As a small meteorite is distributed among institutions which often acquire even less than they desire for their own purposes, it becomes increasingly difficult for others to secure it. Thus, of the 121 meteorites collated by Cohen in 1899 at 65 cents per gram or over, 29 per cent. are not in the 1912 market, whereas of the 120 collated at less than 65 cents, only 6 per cent. have disappeared from current catalogues.

The Cause of High Prices.—On this point an examination of Cohen's collation affords some interesting evidence. He collated 109 meteorites in 1899 which had been recorded by Wülfing in 1897, and of which the major part of each was held by one owner. Classifying them we find that:

1. Seven falls were quoted by four dealers controlling one to two falls each, at figures averaging 68 per cent. lower than Wülfing's values.

2. Sixty-one falls controlled by institutions or private indi-

viduals, were commercially quoted at figures averaging 5 per cent. lower than Wulfing. They controlled one to three falls each.

3. Forty-one falls controlled by the three oldest and largest institutional collections, were commercially quoted at figures averaging 45 per cent. higher than Wülfing. They controlled 8, 12 and 21 falls respectively.

These figures require some analysis before acceptance. It should be emphasized that they are not necessarily institutional prices, but rather prices asked by dealers for institutionally controlled falls.

We have noted that the sixty-one falls controlled by the smaller institutional and private collections afforded market prices 5 per cent. below Wülfing. That meant that their need of each fall controlled was less than the need of the "big three" institutions, whose controlled falls found market prices 45 per cent. higher than Wülfing. The smaller holders let their surplus stock go at low figures on exchange, being eager to advance the growth of their collections, or because they had merely local holdings of a nearby fall, or again because they were uninformed on values. The larger institutional owners, on the contrary, were probably well informed about relative values. Accordingly they parted with their surplus only on the most attractive offers. Moreover they required a larger proportion of each fall than did the smaller collections and had correspondingly less to part with, thus tending to advance the price. Summed up, the price of any fall depends somewhat on how willing the controlling owner is to part with his property, the demand being fully established. However, as with all commodities, such demand varies inversely with the price.

The Use of Wülfing's Tables.—In accepting the much criticized Wülfing formula as the only theoretical system of evaluation yet devised, one must do so with clearly expressed conditions.

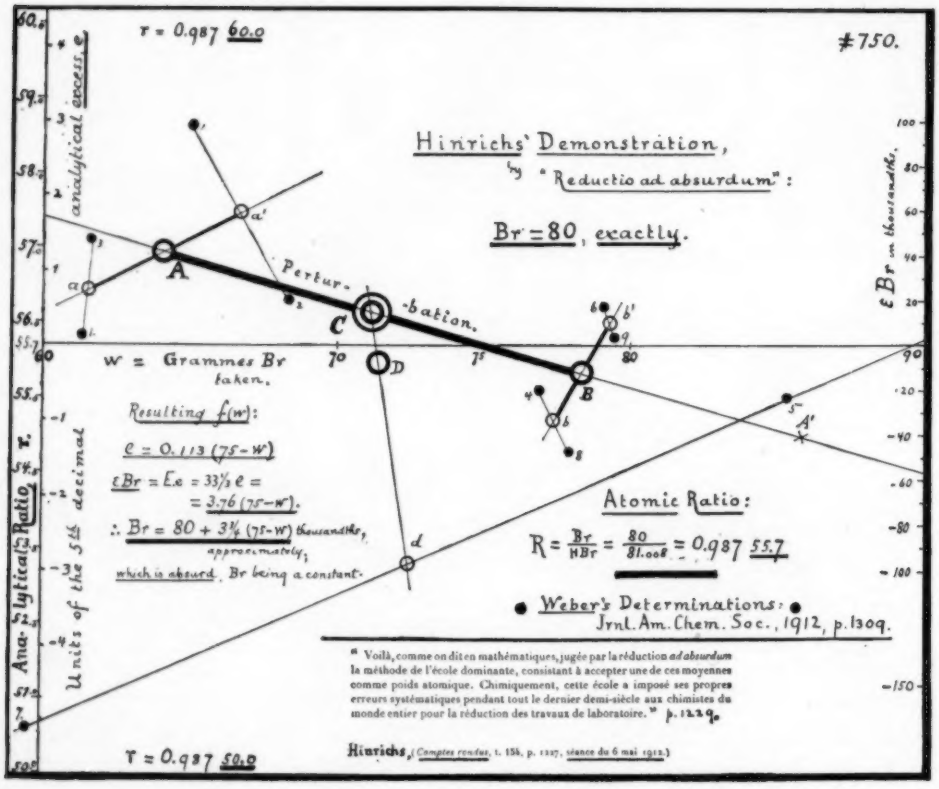
Since some of Wülfing's critics apparently take his approximations as more exact than he intended them to be, let us in fairness read his words on p. 431. "Even though I only succeed in establishing the standard of value to such an extent that one may at least say: the value of such a meteorite is not more than double nor less

than half the given figure—even that would be an advance over the present fearful confusion prevailing on questions of value." While Wülfing's formula has a large probability of error on account of his exclusion of several highly important factors, it must be remembered that without it or some similar system, meteorites would be valued by a "rule of thumb," the elasticity of which is frequently felt in the wide limits shown by exchange and market prices.

It is certain that Wülfing's work has lessened the absurd variations in value which abound in exchanging, and that it has also aided in regulating trade prices. It is therefore to be hoped that a new edition may be published in the not distant future. Nearly two hundred meteorites are known besides the 536 which he recorded, while the number of owners has increased. Unfortunately, Professor Wülfing replies, in response to a query, that he does not contemplate a revision.

Conclusion.—In the writer's opinion, no holder of a meteorite should divide it before considering current trade prices of similar falls, a practice which is already established in the present wide use of previous collations. Likewise he should consult Wülfing's tables, which are based on present known weight, group weight and number of owners. Finally, the exchanger should estimate the importance of the following factors: Weight of specimen offered; observation of fall; area of slice offered; phenomenal variation between individual specimens; distinctness of structure; missing portions; historical interest.

It is certain that the stabilizing influence of a fuller consideration of values by meteorite exchangers will tend to dispel an already lessening hesitation among institutional owners, and result in that freer distribution which Buchner and Wülfing sought to bring about. With its achievement, the advancement of this unfamiliar but growing science will have been distinctly furthered.


r = 0.987 60.0
#750.
Hinrichs' Demonstration,
by "Reductio ad absurdum":
Br = 80, exactly.
Perturbation.
W = Grammes Br taken.
Resulting f(W):
e = 0.113 (75 - W)
εBr = E.e = 33⅓ e =
= 3.76 (75 - W).
∴ Br = 80 + 3¾ (75 - W) thousandths, approximately;
which is absurd. Br being a constant.
Atomic Ratio:
R = Br/HBr = 80/81.008 = 0.987 55.7
Weber's Determinations:
Jrnl. Am. Chem. Soc., 1912, p. 1309.
Analytical Ratio, r.
Units of the 5th decimal
εBr in thousandths.
r = 0.987 50.0

"Voilà, comme on dit en mathématiques, jugée par la réduction *ad absurdum* la méthode de l'école dominante, consistant à accepter une de ces moyennes comme poids atomique. Chimiquement, cette école a imposé ses propres erreurs systématiques pendant tout le dernier demi-siècle aux chimistes du monde entier pour la réduction des travaux de laboratoire." p. 1229.

Hinrichs, (*Comptes rendus*, t. 156, p. 1227, séance du 6 mai 1912.)

THE TRUE ATOMIC WEIGHT OF BROMINE.

(PLATES XXXIV.–XXXVI.)

BY DR. GUSTAVUS HINRICHS.

(*Read April 4, 1913.*)

Highly important laboratory work, undertaken for the purpose of determining the atomic weight of bromine, has quite recently been done by Dr. H. C. P. Weber.[1] Ten complete syntheses of hydrogen bromide were made, taking from 60 to 80 grammes of bromine for the individual determinations.

Employing the method of reduction in general use by the dominant school, Mr. Weber finds the atomic weight of bromine to be 79.924 with the insignificant "*probable error*" of 0.0014, oxygen at 16 exactly being taken as the standard.[2] Accordingly, the atomic weight of bromine should fall between 79.923 and 79.925, for O = 16.

Now bromine is one of the ten fundamental elements of the system of Stas (Ag, Pb, Na, Ka; Cl, Br, Io; N, S, O). If the above value for Br should be found to be in error, such error would affect the values of most of the other nine elements also.

During the last twenty years, I believe to have demonstrated,[3] by close mathematical examination of all the atomic weight determinations made during the entire century (since Berzelius began this work in 1810) that the method in common use for the *reduction* of

[1] *Jrnl. Am. Chem. Soc.*, Oct., 1912, pp. 1294–1310.

[2] *L. c.*, pp. 1309–1310.

[3] *Special Works:* "True Atomic Weights," 1894; "Absolute Atomic Weights," 1901; "Proximate Constituents," 1904. *Twenty-five Notes* in the *Comptes Rendus*, in twelve years from 1892 to 1912; (in nine years no note on atomic weights); *Moniteur Scientifique*, thirteen papers from 1906–1909; *Revue générale de Chimie*, 1910, on hydrogen; *Proceedings American Philosophical Society*, 1910, 1911; *Proceedings Am. Assoc. Adv. Science*, 1869.

PROC. AMER. PHIL. SOC., LII, 211 Q. PRINTED OCT. 14, 1913.

the laboratory work done is not correct but false in principle and erroneous in its results.

Very naturally the dominant school has first denounced my work and thereafter ignored the same; nevertheless it has been compelled to admit the existence of grave errors in the results of Stas which had been extolled to be of astronomical precision. This applies especially to the most famous of the fundamental determinations of Stas, namely those of Ag and N. For nitrogen, Stas gave the value 14.044 exactly. By a marvelous series of decimals (from 38 to 375 places furnished him by A. Quetelet) he declared the lowest *possible* value to be 14.040; at present, the school of Stas has come down to 14.008 which is one fifth of the lowest possible value of Stas and only 8 thousandths above the value we believe to have proved to be the true value, namely 14 *exactly*.[4] For silver the value of Stas has been reduced by his school from 107.930 to 107.880, which is a reduction of fifty thousandths. It must be borne in mind that this matter is a question of high precision, questioning the thousandths of the unit of atomic weights.

All the above values refer to the oxygen standard in common use, O = 16 exactly, for which we believe to have proved that Ag is 108 *exactly* and Br 80 *exactly*. Hence the present values of the dominant school would be 0.120 low for Ag, *i. e.*, 0.11 per cent. of 108; and 0.076 low for Br, *i. e.*, 0.10 per cent. of 80.

If our results are correct, the dominant school is *one tenth of one per cent. low* on the atomic weight of these two fundamental elements.

Accordingly, if our work be true, all the quantitative chemical analyses made in the chemical laboratories throughout the world, from the lowest technical to the highest scientific institutions, have for half a century been falsified (unintentionally, of course, but de facto) to the extent of *one tenth of one per cent.* for both silver and bromine determinations. For lithium, the error committed is now fully one per cent.

[4] The experiments of Guye and his students at Geneva are claimed to prove N = 14.008; but each set of determinations has been made within very narrow limits and with small weights at that, except those of 1912, which positively prove N = 14.000, as I have shown (*Comptes Rendus*, May 6, 1812; T. 154, p. 1227).

The question here raised is therefore of the highest practical as well as scientific importance; most assuredly, it cannot be settled by a ballot, though such has recently been taken. Nor should it be left to the decision of a select few for each country, but every individual chemist should, on this as on any other important chemical question, try to study sufficiently to enable him to form an opinion of his own.

To facilitate such a study on the part of the individual chemist, we here present the laboratory work of Mr. Weber on bromine in the most simple and direct way possible, without any refined technicalities: *simply plotting the experimental results themselves* (the ratios of the actual weights) *according to the weight of the bromine taken and the ratios found in each case.*

When the individual chemist inspects this diagram of the actual weights taken and the ratios found, he will realize that we have neither hypotheses to make nor theories to defend. We simply have tried to look at the actual experimental data obtained in the laboratory itself. We have divided the entire process into twelve consecutive steps, each one being distinct and preparatory to the next.

I. The Weights, Taken and Found.

TABLE I.

Weights, in Grammes, to One-tenth Mgr.

No.	H	Br	HBr	Discrepancy,[5] Mgr.
1	0.7730	61.2884	62.0605	−0.85
2	0.8606	68.2503	69.1114	0.54
3	0.7761	61.5573	62.3220	−1.42
4	0.9693	76.8822	77.8514	−0.15
5	1.0755	85.2956	86.3709	−0.15
6	0.9969	79.0683	80.0642	−0.99
7	0.7497	59.4528	60.2050	2.59
8	0.9816	77.8555	78.8376	0.43
9	1.0013	79.3963	80.3966	−0.06
10	0.8198	65.0214	65.8387	−2.56
Sum	9.0037	714.0572	723.0583	−2.63
Means	0.9004	71.4057	72.3058	−0.26

[5] The discrepancy is: HBr − (H + Br) and its theoretical value is 0, of course. The actual value is once over 1 and twice over 2 mgr.: hence the hundredth mgr. of weighings have properly been dropped by me in copying the weights given by Weber.

II. The Analytical Ratio.

TABLE II.

The Analytical Ratio, r; Calculated to 6 Decimals, the Sixth as First to the Fifth, Since Ordinarily Only Fifth is Taken.

	Ratio:	1st	2d	3d
	Br (to 1st dec.)	H/Br	H/HBr	Br/HBr
1	61.3	0.012 61.2	0.012 45.6	0.987 55.8
2	68.3	60.9	45.2	56.3
3	61.4	61.0	45.3	57.1
4	76.9	60.7	45.1	55.1
5	85.3	60.9	45.2	55.0
6	79.1	60.8	45.1	56.2
7	79.5	61.0	45.2	50.6
8	77.9	60.8	45.1	54.3
9	79.4	61.1	45.4	55.8
10	65.0	60.8	45.2	58.6
Mean	71.4	60.9	45.2	55.5
Range	23.8	0.4	0.5	8.0

Remarks.—(1) Ratios very concordant; range small, especially in first and second (five significant digits only), less so in third (six significant digits). (2) The reciprocal ratios of nos. 1 and 2 would magnify the minute error in H eighty-fold. (3) Complete synthesis gives the three equally important ratios; Weber omits no. 3.

III. The Variation of the Analytical Ratio.

As soon as the individual determinations of the analytical ratio r (Table II.) are plotted according to a convenient scale it is seen that this ratio is not constant, but variable. In our drawing (No. 750) the abscissæ represent the weight w of bromine taken on the scale of a centimeter to the gramme, while the ordinates represent the corresponding ratio r on the scale of one inch to the unit of the *fifth* decimal; that is, the unit-ratio itself is 100,000 inches which is 8,333 feet or 1.58 english mile. Of the three distinct diagrams we shall here insert only the one representing the third ratio, Br/HBr, which is the sharpest and therefore the most decisive. The reduction to centimeter scale by photography is here inserted; for this cut the unit ratio is therefore one kilometer, and the unit of the fifth decimal one centimeter. The gramme is represented by nearly four millimeters. See Plate XXXIV.

Each full black circle represents the determination identified by the same numeral used by Mr. Weber.

The single determinations for less than 60 (no. 7) and for more than 80 grammes (no. 5) of bromine give the mean *d* of comparatively little importance.

The eight determinations made with between 60 and 80 grammes of bromine fall in two well-defined groups of four determinations each and give the equally important two mean values marked *A* (1, 3; 2, 10) and *B* (4, 8; 6, 9) of which *C* is the final mean.[6]

But it is clear that this mean *C* cannot be considered to be the true mean value of the ratio *r* because it is nothing more than the mean of eighth determinations which Mr. Weber made with the eighth weights of bromine which he "happened to take." For as a matter of fact, the eight determinations do not give some constant value from which the individual determinations differ by small deviations equally distributed as to amount and sign. On the contrary, the eight determinations form a well-defined straight line *A–B*, inclined to the axis. Accordingly, it is *this straight line A–B* itself which represents the eight determinations made by Mr. Weber. Only in case the line *A–B* were parallel to the axis of weights taken (horizontal in the drawing) and if, at the same time, all deviations were small, could the point *C* be taken as a legitimate mean.

It is readily seen that the line *AB* is the geometrical representation of the equation

$$r = 57.7 - 0.113w, \qquad (1)$$

where *r* is expressed in units of the fifth place of decimals and *w* in grammes of bromine taken. That is: *r* is *not* a constant, but varies according to the form $k - cw$, where *k* and *c* are constants,

We may express the strange fact revealed in the above by saying that the result of the experiment depends on the choice of the weights taken by the chemist, so much so that "we can tell as soon as the weight has been taken and before the experiment has been

[6] It may be noted that of the two isolated determinations 7 and 5, the first (7) is made with the smallest weight of bromine and therefore shows the greatest deviation, while the last (5) made with the greatest weight of bromine falls distinctly close to the line *AB*.

made, what the outcome thereof will be," or perhaps more strikingly still, we might say that "we get (within sufficiently large limits to count) whatever value r we would like to get."

But the value of r directly determines the value of the atomic weight itself, as we shall show in detail; hence the fact just stated for the ratio applies with equal force to the atomic weight itself.

IV. Systematic Errors and Chemical Perturbations.

The existence of such systematic errors in the most refined laboratory work of renowned chemists, from Stas to the present, is not a new discovery, for I have proved the existence thereof twenty years ago. See the note presented by Berthelot at the Séance of the twelfth of December, 1892.[7]

I here insert (Plate XXXVI.) a reduction to half the original scale of the diagram (no. 215) published in the note just mentioned, together with the diagram (no. 216) of the next note (February 27, 1893). The new cut (no. 752) is a like reduction of Plate I. of my "True Atomic Weights" of 1894 and represents the systematic errors of Stas in his famous syntheses of silver nitrate (no. 251) and of lead nitrate (no. 252). See plate XXXV.

Indeed it is even forty years since I first pointed out the existence of definite *perturbations* (or disturbances) in the chemical work of Stas, namely at the Salem meeting of the American Association for the Advancement of Science in 1869,[8] of which the part here in question is reprinted in my "True Atomic Weights," 1894, pp. 65–69, under the regretfully appropriate heading: vox clamantis in deserto.

We shall, however, in the future restrict the term "chemical perturbation" to such systematic errors as are expressible by a definite function and therefore representable by a definite curve. Such are the systematic errors in the recent work of Mr. Weber, being represented analytically by an equation of the first degree (1) and geometrically by the straight line A–B (cut no. 750, Plate XXXIV.).

[7] *Comptes Rendus*, T. 115, p. 1074.
[8] *Proceedings*, pp. 112–124.

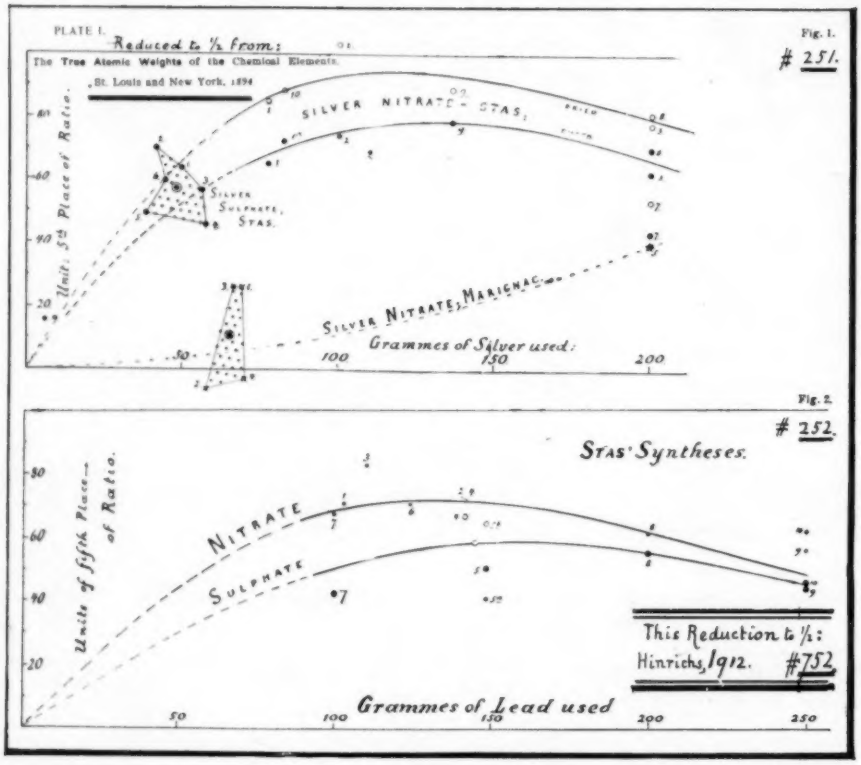
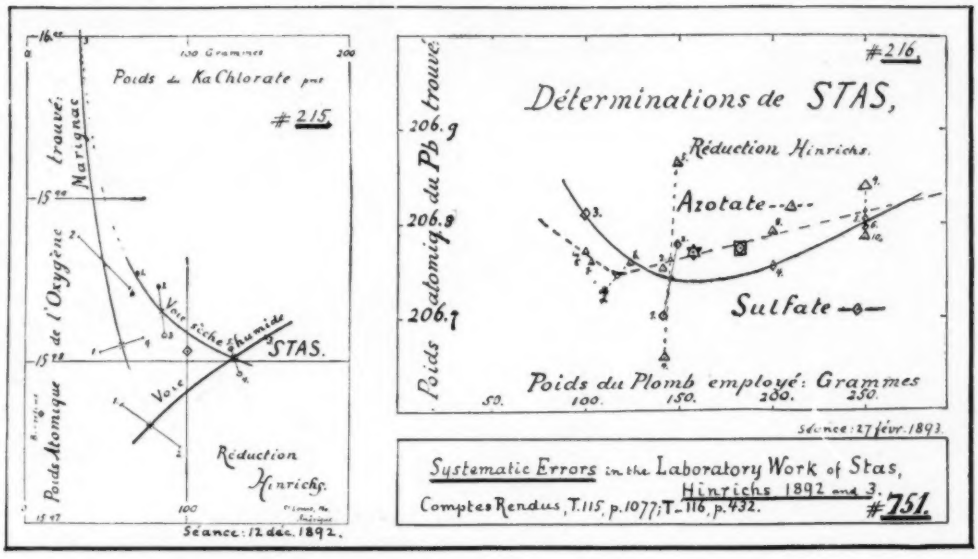


PLATE I.
Reduced to ½ from:
The True Atomic Weights of the Chemical Elements.
St. Louis and New York. 1894
Fig. 1.
251.
SILVER NITRATE - STAS.
SILVER SULPHATE, STAS.
SILVER NITRATE, MARIGNAC.
Units 5th Place of Ratio.
Grammes of Silver used:
50
100
150
200
Fig. 2.
252.
STAS' Syntheses.
NITRATE
SULPHATE
Units of fifth Place of Ratio.
Grammes of Lead used
This Reduction to ½:
Hinrichs, 1912. #752


Poids de KaChlorate pur
#215.
Trouvé: Marignac
de l'Oxygène
Voie sèche humide
STAS.
Voie
Réduction Hinrichs.
Poids Atomique
Séance: 12 déc. 1892.
#216.
Déterminations de STAS,
Réduction Hinrichs.
Azotate
Sulfate
Poids atomique du Pb trouvé
206.9
206.8
206.7
Poids du Plomb employé: Grammes
50.
100.
150.
200.
250.
Séance: 27 févr. 1893.
Systematic Errors in the Laboratory Work of Stas, Hinrichs 1892 and 3.
Comptes Rendus, T. 115, p. 1077; T. 116, p. 432.
#751.

In fact I have communicated to prominent chemists in the United States and in France first proofs of some of my new cuts representing quite a number of such chemical perturbations. All the dominant elements[9] and a number of the others have now been so represented. These first proofs form already quite an atlas. One of these cuts (no. 737) has been published in the *Comptes Rendus* of the meeting of May 6, 1912.[10] It covers work of Richards at Harvard and of Guye at Geneva, on the dominant elements Ag, Cl and N, O, respectively.

By this work we have also introduced into chemistry the method of demonstration of the geometricians of ancient Greece known as the "*reductio ad absurdum,*" which is just as decisive in modern chemistry of precision as in geometry, the highest science of ancient Greece.

V. The Rational Method of Reduction.

This was first published in the *Comptes Rendus* of March 27, 1893 and in my "True Atomic Weights" of 1894. It has been extended and perfected during twenty years, but no complete exposition of all the steps involved having been published in one place at one time, it is no doubt somewhat difficult to grasp and use the same. It is for this reason that we here give, *merely as an example,* its application to the laboratory work of Mr. Weber on bromine.

The old way of successive substitution, producing of necessity an accumulation of errors unknown in magnitude, is based upon the elementary method of solving an algebraic equation with supposedly one unknown only, when in fact it contains as many unknown as there are elements present in the chemical reaction employed. Since, however, in a chemical reaction it is impossible to accept any one element as without error in its action, all these equations are de facto indeterminate (or diophantic) and therefore insoluble. The solutions given by the school are therefore erroneous and cannot be in accord with the facts.

But while the work of the school during the entire century has thus necessarily failed to give a true solution of the problem by that

[9] *Comptes Rendus,* T. 153, p. 817; 30 Oct., 1911.

[10] T. 154, p. 1228.

method, it has established incidentally one general fact of great practical importance, namely that all the atomic weights are approximations to certain whole or half numbers, if the atomic weight of oxygen is taken at 16 exactly.

Consequently we may say that the entire mathematical problem will require only the exact determination of the value of this small *departure* (which we now represent by the Greek letter epsilon ϵ).

Every mathematician knows that all relations, even the most complex, are thereby reduced to simple proportions. Hence all our calculations can be carried out by proportional parts, if the necessary relations have first been deduced either by geometry or by development into series. We have used both methods. After overcoming these difficulties we have systematized the work by simple analytical processes, retaining however the general geometrical method for the presentation of the data of experiment and the results of calculation, as exemplified above and in our numerous diagrams of which reductions by photography are printed.

It seems best, at this point, to state the degree of precision aimed at: the third decimal (thousandths) of the atomic weight and the fifth decimal (hundred thousandths) of the ratios (atomic R and analytic r). If at any time we feel authorized to go beyond this general limit, the higher decimals are given as decimals to the above, in order to conform to definitions given and to avoid confusion.

VI. The Departure, ϵ.

The true atomic weight of bromine is known to be some value quite near the number 80; all chemists admit this as an established fact. *Hence we limit our work to the determination of the precise small number of thousandths of the unit, our departure* ϵ.

Accordingly we say: the exact atomic weight of bromine is $80+\epsilon$. We then perform all analytical operations with this sum instead of using the one symbol Br. Thus many terms will cancel and others will drop out as minute quantities of too high an order to be of influence on the result: facts and processes familiar to all those versed in mathematical work. In this way we finally obtain readily workable formulæ. (See p. 61 of our "Cinquantenaire,"

1910, for an example and note the interesting story of its wanderings in 1907 and 1908.) This may be sufficient for the present to direct those readers who may need such reference.

We now return to the simple practical details necessary for carrying out the work of determining the small departure ϵ for bromine.

VII. The Atomic Ratio R, and its Variation Δ

To express the chemical reaction used, we first take the departure as zero (that is Br = 80 exactly and H = 1.008 to the nearest thousandth), as we have shown it to be in our history of all determinations for hydrogen made in the century past.[11] This gives us R and Δ as shown in Table III. by elementary mathematics.

TABLE III.

Ratio for	1st H/Br		2nd H/HBr		3rd, Br/HBr	
First, for Atomic ratio	Br = 80 / 1.008 / 80		and / 1.008 / 81.008		H = 1.008 / 80 / 81.008	
which is R =	0.012	60.1	0.012	44.4	0.987	55.7
Second, for Atomic ratio	Br = 80.1 / 1.008 / 80.1		and / 1.008 / 81.108		H = 1.008 / 80.1 / 81.108	
which is R' =	0.012	58.5	0.012	42.9	0.987	57.2
hence ΔBr = $R' - R$ =		−1.6		−1.5		+1.5
Third, for Atomic ratio	Br = 80 / 1.108 / 80		and / 1.108 / 81.108		H = 1.108 / 80.0 / 81.108	
which is R'' =	0.013	85.1	0.013	66.2	0.986	33.9
hence ΔH = $R'' - R$ is		125.0		121.8		−121.8

[11] *Revue gén. de Chimie*, 1910, 377–389.

VIII. The Analytical Excess *e*.

This is the number of units of the fifth decimal by which r exceeds R; that is

$$e = r - R. \qquad (2)$$

Table II. gives the following results:

TABLE IV.

Values of the Analytical Excess, *e*.

No. R_{Ag}	W Br (grammes)	1 H/Br 0.012 60.1	2 H/HBr 0.012 44.4	3 Br/HBr 0.987 55.7
1	61.3	1.1	1.2	0.1
2	68.3	0.8	0.8	0.6
3	61.4	0.9	0.9	1.4
4	76.9	0.6	0.7	−0.6
5	85.3	0.8	0.8	−0.7
6	79.1	0.7	0.7	0.5
7	59.5	0.9	0.8	−5.1
8	77.9	0.7	0.7	−1.4
9	79.4	1.0	1.0	0.1
10	65.0	0.7	0.8	3.0
Mean	71.4	0.8	0.8	−0.2

The concordance between r (experiment) and R (absolute value) is almost perfect, $e = r - R$ affecting the millionths almost exclusively (in all but four of the thirty cases!).

If we were to decide by mean values, in accordance with the common practice of the school, we would have to conclude that *the true atomic weight of bromine is 80 exactly;* for the mean analytical excess is only 8 millionths above in the first and second ratios and merely 2 millionths below in the third ratio. This implies a truly marvelous approximation to our absolute atomic weight Br = 80 exactly.

Since the third ratio is mathematically the sharpest, being near unity, we might claim in truth having demonstrated with "astronomical precision" that the atomic weight of bromine is 80 exactly.

By means of the known value of the variation Δ we can readily convert the value of the analytical excess into the corresponding departure ϵ in thousandths of the unit of atomic weights.

IX. The Variation of the Analytical Excess, *e*.

The mere fact that the mean value of the excess *e* is very small (0.2 only) is, however, not sufficient to completely establish the conclusion just drawn, as we have always accentuated; for some of the individual values of the excesses might be large with opposite sign, or show notable *systematic variations*—this they do in fact in the present case.

Hence it is necessary to study the individual values of the analytical excess for each laboratory determination made. They are given in Table IV. of section VIII., in the last column. By simply drawing (on diagram no. 750) the base line (horizontally) through the point on the scale of the analytical ratios for the value of the atomic ratio, $R=0.98755.7$ (see VII.), we get the representation of *e* on the diagram. This horizontal line is shown on our cut no. 750, which thus exhibits the exact value of the analytical excess for every individual determination made. See Plate XXXIV.

Taking this line as the new axis of abscissæ for *e* the equation of the line of perturbation will be

$$e=0.113(75-w). \qquad (3)$$

It is not necessary to discuss this equation, since it corresponds exactly to that for *r* already considered in III.

X. The Increment, Σ.

Σ is the change in the third decimal of the atomic weight produced by one unit in the fifth place of the analytical ratio *r*.

It will be impossible to enter here upon the complete deduction of the formulæ now to be presented for practical work; for our deduction we must refer to a series of papers in the *Comptes Rendus* from 1907 to the present and to our publications in other quarters, especially including the facsimile of a general deduction which has travelled between Paris and St. Louis in 1907 and again in 1908; see p. 61 of my "Cinquantenaire de L'atomécanique, 1910," under the title: Un Manuscrit Voyageur. All these more recent develop-

ments of general formulæ really go back to 1894 in my "The Atomic Weights," pp. 157–161. On p. 159 will be found the formula (42) for the chemical perturbation, essentially the same as the one we have been using for a number of years.

In fact, it would be interesting to trace the development we have been able to make of the method of Lagrange so renowned with mathematicians and astronomers under the name of "The Method of the Variation of the Arbitrary Constants."

Our simplest formula, obtained by means of Taylor's most general formula, for m chemical elements present in the reaction, is

$$\Sigma\epsilon\Delta = 100e. \tag{4}$$

Treating the effect of the elements ex-æquo, this equation becomes

$$m\epsilon\Delta = 100e, \tag{5}$$

or simply

$$\epsilon = \Sigma e; \tag{6}$$

if we introduce the increment Σ as defined above

$$\Sigma = 100/m\Delta, \tag{7}$$

which also may be defined as the departure per unit of the excess e.

In the case under consideration we have the variation determined in VIII., while the number of elements present (m) is 2 (Br and H); hence the third reaction (the sharpest) gives the values of the departures presented in the next section XI. as Table V.

XI. Summary of Results Obtained for the Reaction $R = Br : HBr$.

TABLE V.

I. The Arbitrary Constants α (*i. e.*, the Absolute Atomic Weight) and their Variation (Δ, Σ).

	Elements	
	Br	H
Absolute atomic weight, α	80	1.008
Variation, Δ (units of fifth place)	1.5	— 121.8
Increment, Σ (units of third place)	$33\frac{1}{3}$	— 0.41
Departure, ϵ, by e	$33\frac{1}{3}$e	— 0.41e

II.—Mean Values of Departures, ε.

Point	Experiments	w	e	eBr	eH
A	1, 2, 3, 10	64.0	1.25	41.5	—0.51
B	4, 6, 8, 9	78.3	—0.35	—11.7	0.14
	Mean of groups A and B.				
C	*A, B*	71.61	0.45	15.0	—0.18
	Mean of all Determinations.				
D	*C, d*	71.77	—0.22	— 7.3	0.09
Departure as function of $w' = 75 - w$				$3.77w'$	$-0.05w'$

III.—Mean Atomic Weights.

Point	Experiments	w	e	Br	H
A	1, 2, 3, 10	64.0	1.25	80.042	1.0075
B	4, 6, 8, 9	78.3	—0.35	79.988	1.0081
	General Means.				
The 2 groups of four determinations each:					
C	*A, B*	71.61	0.45	80.015	1.0078
All ten determinations:					
D	*C, d*	71.77	—0.22	79.993	1.0081

IV.—True Atomic Weight.

For all possible weights, *i. e.* entire line:

Point	Experiments	w	e	Br	H
A — *B*	1,2,3,4,6,8,9,10	71.61	0.00	80.000	1.0080

Note.—Confirmatory determinations desirable especially for weights symmetrically taken in reference to *A* and *B;* that is for mean weights of about 86 and 72 grammes.

Reference: "True Atomic Weights," 1894, p. 158.

XII. General Conclusion.

It will have been noticed that our work really gives *three* distinct demonstrations that the atomic weight of Bromium is 80 exactly.

First (as shown above in VIII.), by the *limit-method,* the means closely approaching the value Br = 80 exactly.

This method was first published in the *Comptes Rendus* from 1892 to 1894 when it was more fully developed in my book: "The True Atomic Weights," 1894, of which Berthelot accepted the dedication.

Second. By the "Chemical Perturbations," representing all determinations by a single straight line, intersecting the axis of abscissæ of weights taken.

This also demonstrates completely that the true atomic weights *cannot* be determined by empirical methods alone.

In fact, the empirical methods lead really more and more away from the truth by the chemists trying to secure greater concordance —which can most easily be reached by limiting the range of weights taken (as already shown here) and in many other ways, all leading into error. We hope soon to take up this most important practical subject more thoroughly.

Third.—By the *reductio ad absurdum,* showing that the atomic weight for the individual determination is de facto a function of the weight taken for effecting the determination; this result is evidently absurd, because the atomic weight in its very nature is independent of the amount or weight of the substance operated upon.

In other words: the individual determinations establish the line of perturbation only, the intersection of which with the axis of weights taken (for $e=0$) gives the true solution for all experiments represented on that line of perturbations.

Final Conclusion. While each one of these three demonstrations, taken separately, is sufficient to prove that the true atomic weight of bromine is 80 exactly, they properly constitute three consecutive steps in *one complete demonstration* which itself has been gradually developed in that order above given. It may be best to repeat them here as links of that chain of demonstration:

1. The values of the analytical excess e are minute and of opposite sign, giving a mean more or less closely approaching to zero; hence the horizontal line $e=0$, determined theoretically by the atomic ratio R, is the locus of the true atomic weight.

2. The straight line of perturbation is a second locus of the same; *hence the intersection of these two lines determines the weight for which the laboratory work is without error.*

3. The other parts of the line of perturbation give the atomic weight as function of the weight taken for the experiment, which being absurd, proves that they only serve to determine the point

of intersection, as just done. Besides: each single point in the line of perturbation *above* the point of intersection is balanced by the equal value of contrary sign *below* that line symmetrical with the above point.

Trusting that we have made this subject as clear as so difficult a matter—at first reading—may be made, we shall add only that all thought of the so-called "probable error" of the mean must be laid aside in atomic weight determinations; we have repeatedly shown its utter absurdity in this field—the more careful laboratory work having the desperate character of placing itself squarely far beyond the field restricted for it by the so-called "probable error of the mean" so as to leave it not a shred of probability. We expect as soon as possible, by a most striking example (covering all the work done for an important element) to show the utter fallacy of this "probable error of the mean" introduced by Gauss a century ago. We shall, at the same time, show that it is but a false and misleading substitute for the simple mean value of the actual distance of each determination from the mean of all.

We here insert, from a most extended table carefully classified by order of magnitude and for each individual element separately, giving the most general results in a broader grouping, to show the fact referred to above: that with progress in practical laboratory work, the final departure has been greatly reduced.

The four catalogues of work represent: (*A*) recent and classical work (Dumas, Stas to present); (*B*) older determinations (except the classical); (*C*) dominant elements only: *i. e.*, O, Cl, Ag; C, Na; S, Br, H; N, Ka.

PER CENT. OF EACH GRADE SPECIFIED.

Grade in Words	ϵ	Catalogue				
		B	AB	A	C	
Excellent to good	Below 100	77	85	93	98	per 100
Poor to bad	Above 100	23	15	7	2	per 100
Number of:						
Determinations		508	967	459	159	
Reactions		163	340	177	53	